

**Zebra (*Dreissena polymorpha*) and
Quagga Mussel (*Dreissena bugensis*)
Distribution and density in Lake Erie,
1992-1998.**

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**ZEBRA (*Dreissena polymorpha*) AND QUAGGA MUSSEL (*Dreissena bugensis*)
DISTRIBUTION AND DENSITY IN LAKE ERIE, 1992-1998.**

by

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ABSTRACT

Jarvis, P., Dow, J., Dermott, R., and Bonnell, R. 2000. Zebra (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena bugensis*) Distribution and Density in Lake Erie, 1992-1998.

A benthic survey was conducted in Lake Erie in 1998 to determine zebra (*Dreissena polymorpha*) and quagga mussel (*Dreissena bugensis*) densities and biomass and to compare with data from surveys conducted in 1992 and 1993. Two shoal sites were sampled in 1998, one each in the eastern and western basins, to compare *Dreissena* densities on the rocky shoals with that on softer substrates. *Dreissena* densities on soft sediments in Lake Erie averaged 3712 m^{-2} in 1998 with a range of 0 to $31\,208 \text{ m}^{-2}$. Densities were an order of magnitude greater on the rocky shoals than on softer sediments. On the softer sediments, density and biomass in 1998 were greatest in the eastern (4826 m^{-2} ; 568 g/m^2) and central (3676 m^{-2} ; 878 g/m^2) basins compared to only 418 m^{-2} ; 203 g/m^2 in the western basin. Quagga mussels were 100% of the mussels on the eastern Nanticoke Shoal and averaged 84.8%, 99.7% and 36.9% of the *Dreissena* populations in the eastern, central and western basins respectively, but less than 6% on the western Sunken Chicken Shoal. Total combined *Dreissena* density was greatest in the 5-10 m depth range (6419 m^{-2}). Quagga mussels dominated at all depth ranges except for the 0-5 m range (591 m^{-2}) where zebra mussels predominated (2335 m^{-2}). Alternatively combined *Dreissena* biomass was greatest in the 20-30 m depth range (1229 g/m^2). Mean filtering rates ranged from 614 ml/hr/m^2 to $280\,730 \text{ ml/hr/m}^2$ at site 942. The calculated filtering rate exceeded $100\,000 \text{ ml/hr/m}^2$ at four sites (E3, 942, C2 and W5) across the three basins. The estimated mortality rate in the offshore zone was 11.5% in the eastern basin and 29.8% in the central basin, with the majority of dead shells being in the smaller size classes ($< 12 \text{ mm}$). *Dreissena* density was greatest at the 2 m depth of both rocky shoals ($68\,529$ and $68\,547 \text{ m}^{-2}$ at Nanticoke and Sunken Chicken shoals respectively), while alternatively the biomass increased with increasing depth (3708 to 4524 g/m^2 and 1670 to 4413 g/m^2 at Nanticoke and Sunken Chicken shoals respectively). *D. polymorpha* density at the Sunken Chicken shoal has decreased since 1990, while the mean valve length and weight have increased. Based on 16 matched sites, lake wide combined *Dreissena* biomass increased between 1992 and 1998, from 371 to 958 g/m^2 . The increase in biomass resulted from an increased quagga mussel population (886 to 5729 m^{-2}) and an increasing mean valve length. At these 16 matched sites, the average *D. polymorpha* abundance declined (3114 to 2 m^{-2}) over the same time period.

RÉSUMÉ

Jarvis, P., Dow, J., Dermott, R., and Bonnell, R. 2000. Zebra (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena bugensis*) Distribution and Density in Lake Erie, 1992-1998.

En 1998, on a effectué un relevé benthique dans le lac Érié pour déterminer la densité et la biomasse de moules zébrées (*Dreissena polymorpha*) et de moules quaggas (*Dreissena bugensis*) et pour comparer les résultats obtenus avec les données de relevés menés en 1992 et 1993. Deux hauts-fonds ont été échantillonnés, l'un situé dans le bassin est, et l'autre, dans le bassin ouest, afin de comparer la densité de *Dreissena* sur les hauts-fonds rocheux et sur les substrats mous. D'après le relevé, la densité moyenne de *Dreissena* vivant sur des sédiments mous du lac Érié était de $3\,712\text{ m}^{-2}$ en 1998 (la densité variait entre 0 et $31\,208\text{ m}^{-2}$). La densité observée sur les hauts-fonds rocheux était plus élevée d'un ordre de grandeur que sur les sédiments mous. Sur les sédiments mous, on a observé la densité et la biomasse les plus hautes dans les bassins est ($4\,826\text{ m}^{-2}$; 568 g/m^2) et central ($3\,676\text{ m}^{-2}$; 878 g/m^2). La densité dans le bassin ouest, quant à elle, s'élevait seulement à 418 m^{-2} ; 203 g/m^2 . Les moules quaggas formaient 100 % de la population de moules sur le haut-fond Nanticoke (est). Dans les bassins est, central et ouest, elles représentaient en moyenne 84,8 %, 99,7 % et 36,9 % des *Dreissena* respectivement. Toutefois, sur le haut-fond Sunken Chicken (ouest), elles ne constituaient que 6 % de la population. On a noté la plus forte densité des deux espèces de *Dreissena* combinées dans la gamme des profondeurs de 5-10 m ($6\,419\text{ m}^{-2}$). Les moules quaggas dominaient toutes les gammes de profondeurs, sauf celle de 0-5 m (591 m^{-2}), où les moules zébrées prédominaient ($2\,335\text{ m}^{-2}$). Par contre, la biomasse la plus élevée des deux *Dreissena* combinées se trouvait dans la gamme de 20-30 m ($1\,229\text{ g/m}^2$). Les taux de filtration moyens allaient de 614 ml/hr/m^2 à $280\,730\text{ ml/hr/m}^2$ au site 942. Le taux de filtration calculé dépassait $100\,000\text{ ml/hr/m}^2$ à quatre endroits (E3, 942, C2 et W5) dans les trois bassins. Le taux de mortalité estimé dans la zone du large était de 11,5 % dans le bassin est et de 29,8 % dans le bassin central. Par ailleurs, la majorité des coquillages morts faisaient partie des catégories de tailles inférieures ($< 12\text{ mm}$). On a trouvé la plus haute densité de *Dreissena* à 2 m de profondeur, et ce, sur les deux hauts-fonds rocheux étudiés ($68\,529\text{ m}^{-2}$ à Nanticoke et $68\,547\text{ m}^{-2}$ à Sunken Chicken), alors que la biomasse augmentait avec la profondeur (de $3\,708$ à $4\,524\text{ g/m}^2$ à Nanticoke et de $1\,670$ à $4\,413\text{ g/m}^2$ à Sunken Chicken). La densité de *D. polymorpha* sur le haut-fond Sunken Chicken a diminué depuis 1990, tandis que la longueur et le poids moyens de leurs coquilles ont augmenté. D'après des études effectuées dans 16 sites appariés, la biomasse des deux espèces de *Dreissena* combinées dans l'ensemble du lac est passée de 371 à 958 g/m^2 entre 1992 et 1998 en raison de l'augmentation de la population de moules quaggas (886 à $5\,729\text{ m}^{-2}$) et de la longueur moyenne des coquilles. Dans les 16 sites appariés, l'abondance moyenne des *D. polymorpha* a décliné (de $3\,114$ à 2 m^{-2}) pendant cette même période.

INTRODUCTION

The zebra mussel (*Dreissena polymorpha*) was introduced into the Great Lakes around 1987 and had colonized most of the hard substrates in the nearshore areas of Lake Erie by 1989 (Griffiths et al. 1991). A second *Dreissena* species was discovered in the lower Great Lakes in 1989, and was identified as the quagga mussel (*D. bugensis*) (Spidle et al. 1994). The quagga mussel can survive on softer substrates and at greater depths than the zebra mussel allowing it to flourish in the central and eastern basins of Lake Erie (Dermott and Munawar 1993; Mills et al. 1993). As a consequence, these two *Dreissena* dominate in both the littoral and profundal zones of Lake Erie (Dermott and Kerec 1997).

Dreissena mussels can have substantial ecological impacts on lake food webs as well as planktonic and benthic communities (Nalepa and Fahnenstiel 1995). They may remove up to 62% of annual littoral algal production (Hamburger et al. 1990), and are credited with causing reductions of phytoplankton biomass in Lake Erie (Wu and Culver 1991; MacIsaac et al. 1992; Leach 1993; Nicholls and Hopkins 1993; Madenjian 1995 and Stoeckmann and Garton 1997). Furthermore, they may reduce planktonic herbivore abundance through competition for phytoplankton, thus affecting the food availability for planktivorous fish (Young et al. 1996) and competition for space with native Unionidae (Mackie 1991; Schloesser et al. 1998).

Typically, the initial *Dreissena* introduction to an area outside of their native range results in a population explosion, often by a factor of 2 to 3, lasting for several years, followed by a decline and, finally stabilization of the population (O'Neill and MacNeill 1991). An increasing population suggests the impacts that *Dreissena* mussels have on the phytoplankton will likely increase unless mussels ingest a substantial proportion of required calories from nonplanktonic sources (Cotner et al. 1995; Lavrentyev et al. 1995). While their impact on the aquatic environment is assumed to be density-dependent (Griffiths 1993), population size structure is also an important factor (Young et al. 1996). Quantification of the *Dreissena* population size and structure is necessary for predictions of trophic consequences of this invasive species in Lake Erie.

The objective of this study was twofold: (1) to determine the current distribution of the mussels and estimate their filtering rates, and (2) to determine any changes in composition, density and size of the mussels at the same sites between 1990 and 1998.

METHODS

SAMPLE COLLECTION

During April - June and September of 1998, 30 sites on silts, sand and gravel sediments in Lake Erie were sampled for the occurrence of *Dreissena* mussels: 7 in the western basin, 9 in the central basin and 14 in the eastern basin (Fig. 1). Data at these sites were compared to data collected in 1992 and 1993 (Appendix 1 and 2) based on the site locations shown in Figure 2. Site locations were based on GPS co-ordinates for all three years as given in Table 1 and Appendix 3.

From one to five benthic samples were collected using mini-PONAR grabs (area 0.022 m²) at each site, except for site E1 which was sampled using a large-PONAR grab (0.053 m²) to ensure sampling on coarse gravel. Each sample was sieved through a 250µm net and preserved in 8% neutral formalin. In the laboratory the samples were re-sieved through a 1 mm mesh screen. The mussels retained on the 1 mm screen were separated as either zebra or quagga mussels and enumerated. The lengths of the mussels were measured to the nearest 0.1 mm from the umbo at the hinge to the furthest posterior part of the shell using electronic calipers to calculate length-frequency distributions. Biomass was calculated as a wet weight with shells by blotting the mussels on filter paper to remove excess water and weighing to the nearest 0.01 mg.

Shoal Sites

Nanticoke Shoal in the eastern basin and Sunken Chicken Shoal in the western basin (Fig. 1) were sampled August 11 and September 10 of 1998, respectively. The Sunken Chicken Shoal site was chosen to correspond to sampling that was performed there in 1990 and 1991 (Fitzsimons et al. 1995). Site locations were based on GPS co-ordinates as given in Table 1.

Cobbles were collected at three depths (2, 3 and 4 m) from the Sunken Chicken shoal and two depths (3 and 4 m) from the Nanticoke shoal. No area shallower than 3 m was found at the Nanticoke shoal preventing sampling at 2 m. Because of the physical impracticality of counting mussels on the bedrock, small individual cobbles (20-50 cm) were returned to the surface by divers. All live mussels within 5 × 5 cm quadrat (mussels that were not completely in the quadrat were counted if their hinge was in the quadrat) were removed from individual cobbles and screened on a 1mm mesh. The mussels retained on the 1mm mesh were separated by species, enumerated to determine density m⁻² and measured to determine length-frequency distributions. Biomass of the mussels at the rocky shoals was calculated as dry weight (including shells) after air drying the mussels and weighing to the nearest 0.01 mg.

STATISTICAL ANALYSES

Analysis of variance (ANOVA) and Student's t-tests were used to determine the significance of basin, year and depth effects on *Dreissena* density and biomass. Data were logarithmically transformed as natural logs to obtain homogenous distribution of variance. Two-way ANOVA was used to test the significance of interactive effects of year and basin relative to combined *Dreissena* biomass and density. For pairwise comparisons the Bonferroni test was used to test the significance of differences among the means. Statistics were performed using SYSTAT 6.0 (Wilkinson 1996).

1998 Comparisons

One-way analyses of variance (ANOVA) was employed to compare quagga, zebra and combined mussel densities and biomass by basin (three factors; east, west and central) and by depth strata (five factors; 0-5, 5-10, 10-20, 20-30 and 30+ m).

Length-frequency histograms were plotted as the percentage of total animals in 1-mm size classes from 1 to 30 mm. The majority of mussels with shell lengths of less than 2 mm pass through the 1mm mesh and were thus not included in the analysis. The histograms of the shell lengths were used to compare living and dead animals at four sites (930, E2, EC2 and C2), living animals were defined as animals that were alive at the time of sampling, while dead animals were empty articulated shells or pairs of single shells at the time of sampling.

Profundal zone mortality rates were calculated at four sites below 30 m in the eastern basin (930, E2, E4, and 940) and at three sites below 20 m in the central basin (EC2, C2 and 954). Average numbers of living and dead mussels per mini PONAR sample were calculated to determine the percentage of empty mussel shells at each site. Deeper offshore sites were selected for these comparisons to minimize the chances of counting shells that had not died at the site but had been washed to the site by currents and winter storms.

Filtration rates (ml/mussel/hr) were determined as per Reeders et al. 1993 based on mean valve lengths for sites that had a minimum of 20 shells for measurement. Filtration rate was calculated as: $F.R. (ml\ hr^{-1}\ individual^{-1}) = 15.43 / (0.293 + 52.38 e^{-0.367\ length\ mm})$ $r^2 = 0.59$
Filtration rate was converted to rate per m² using average mussels density at each site.

1992-1998 Comparisons

Data from 16 matched sites (n = 179 samples), which were sampled each year in 1992, 1993 and 1998, were used to compare *Dreissena* abundance and biomass over the years. This matched data set consisted of 3 sites in the western basin, 7 in the central basin and 6 sites in the eastern basin. One-way ANOVA's were performed on the data from the 16 matched sites sampled on each of the years. Comparisons were made of the quagga, zebra and combined mussel densities and biomass among years (three factors; 1992, 1993 and 1998, n= 179 samples). A two-way ANOVA was performed to compare year and basin interaction of combined *Dreissena* spp. density and biomass.

Length-frequency histograms were plotted as the percentage of total animals present in 1-mm size classes from 1 to 30 mm. Data from the eastern basin sites 933, E2 and E3 were used to compare length-frequency histograms between 1993 and 1998 and at site 940, data from 1992, 1993, 1994 and 1998. For the central basin, data from site 951 in 1993 was compared to that from nearby site C2 in 1998. No comparisons were made for the western basin due to lack of previous length-frequency data at the sites.

Shoal Comparisons

Student's t-test and ANOVA's were used to compare mean biomass and density at the shoals. Combined *Dreissena* densities were compared across three depths for Sunken Chicken shoal and two depths for Nanticoke shoal in 1998, as outlined above. Furthermore, a histogram was created to compare the size frequency of the mussels at 3 m at Nanticoke and Sunken Chicken shoals in 1998. Tests were performed with Sunken Chicken shoal data to compare 1998 combined *Dreissena* densities at 2, 3 and 4 m against the data from 1990 and 1991 (Fitzsimons et al. 1995).

Length-frequency histograms were plotted for the population on Sunken Chicken shoal at 3 m in 1998 and compared to data from Sunken Chicken shoal in 1990 and 1991 at 3m. Based on the length frequency distributions in 1990 and 1993 (Fitzsimons et al. 1995) and the length - weight ratio (Dermott et al. 1993), the biomass of the *Dreissena* population at Sunken Chicken shoal was calculated for 1990 and 1993. ANOVA's were done to compare the biomass at Sunken Chicken shoal in 1990 and 1993 with that in 1998.

RESULTS

1998 DISTRIBUTIONS

Quagga mussels occurred at 23 of the 30 sites sampled with a PONAR in 1998, while zebra mussels were present at only 6 sites (Table 2). These included 3 sites in the eastern basin < 3 m deep, and 3 sites in the central and western basins. No mussels were present at most of the soft bottomed sites in the western basin. In 1998, the combined *Dreissena* density at the 30 sites averaged 3712 m^{-2} (Standard Error, SE = 746 m^{-2} ; $n = 75$), while the combined *Dreissena* wet biomass averaged 578 g/m^2 (SE = 151 g/m^2 , wet +shells). Density ranged from 0 m^{-2} at seven sites to 31208 m^{-2} at site E3 on glacial till (Fig. 3), and the biomass reached a high of 3377 g/m^2 at site C2 (Fig. 4).

Basin Comparisons

Mean combined *Dreissena* density in 1998 ranged from 418 m^{-2} in the western basin to 4826 m^{-2} in the eastern basin (Table 3). Average combined *Dreissena* biomass ranged from 203 g/m^2 in the western basin to 878 g/m^2 in the central basin (Table 3 and Fig. 5).

Density and biomass of quagga mussels and combined *Dreissena* mussels had significant inter-basin differences. Both the density and biomass of combined *Dreissena* were lower in the western basin than the central ($p < 0.001$) and eastern basin ($p < 0.001$ for biomass; $p < 0.05$ for density). Quagga mussel density was also lower in the western basin as compared to the central ($p < 0.001$) and eastern basins ($p < 0.001$), whereas the quagga mussel biomass in the western basin was not significantly less than in the central basin but it was less than that in the eastern basin ($p < 0.01$) (Table 3).

Zebra mussels were almost completely absent in the central basin where quagga mussels made up 99.9% of the *Dreissena* population (Fig. 3). Quagga mussels also predominated in the eastern basin but only formed 37% of the *Dreissena* community in the western basin during 1998. Although no significant inter-basin difference in zebra mussel biomass was found, density of zebra mussels was greater in the eastern (723 m^{-2}) than the central basin (2 m^{-2}) ($p < 0.05$) due to the high density at the shallow sites in Inner Long Point Bay (Fig. 3).

Depth Comparisons

Combined *Dreissena* densities ranged from 2927 m^{-2} in the 0-5 m depth range to 6419 m^{-2} in the 5-10 m depth range (Table 4 and Fig. 6). *Dreissena* spp. density was consistent at all depths below 10 m. In Lake Erie, all depths >26 m are in the eastern basin, therefore the high biomass in the 20-30 m zone represents the high biomass in the deeper eastern basin. Mean combined *Dreissena* biomass ranged from 214 g/m^2 in the 0-5 m depth range to 1299 g/m^2 in

the 20-30 m depth range (Table 4 and Fig. 6). Although no significant inter-depth differences in density or biomass of either combined *Dreissena* or quagga mussels alone were found, densities and biomass of zebra mussels were significantly greater in the 0-5 m depth range than the other four depth ranges ($p < 0.001$). In the eastern basin, the majority of the zebra mussels were found at the shallow sites (< 5 m) of Inner Long Point Bay, often attached to the submerged macrophytes.

Filtering Rates

For sites having a sufficient number of mussels to measure the average population length ($n > 20$), the calculated optimal summertime filtering rates ranged from a low of 1.24 ml/hr/mussel at site EC1 to 43.79 ml/hr/mussel at W5 (Table 5). Mean filtration rates based on *Dreissena* densities at each site ranged from 614 ml/hr/m² at site EC1 to 280 730 ml/hr/m² at site 942 (Table 5). Eleven sites are not represented in the table due to either absence of mussels in the samples (M29, WC2, 967, 971, W6, W7 and W8) or too few mussels present to allow calculation of an accurate mean valve length (E1, 954, 956 and W3).

Average filtering rate at sites in the eastern and central basin shallower than 15 m was 5.04 ml/hr/mussel compared to 14.91 ml/hr/mussel at sites beyond 15 m depth combined with the average density of 6419 m⁻² at 5-10 m, optimal filtration inshore was calculated as 32.35 L/hr/m⁻² compared to 51.16 L/hr/m⁻² for the 20-30 m contour of the lake. Estimated mid summer filtration in the western basin would be much less than the 99.57 L/hr/m⁻² at site W5 as most sites in the western basin on soft bottom had no live mussels.

Offshore-Zone Mortality Rates and Length-Frequency Distributions

The estimated mortality rate in the offshore zone, based on the percentage of live and dead mussels in the samples, was 11.5% in the eastern basin and 29.8% in the central basin. The range was from 2.4% at site 940 in a depth of 47 m, to 24.4% at site E2 (38 m depth) in the eastern basin, and from 25.4% at site C2 at 22 m, to 51.5 % at site EC2 (22 m) in the central basin (Table 6). These estimates of mortality assume that mussels which die remain in place and the shells do not dissolve when buried in the sediment. These values would be maxima, as they do not take into account an accumulation of shells in the sediments over the 10 year period (1989-1998) that *Dreissena* have been present on the sediments of eastern Lake Erie.

Length-frequency histograms were produced to compare size distributions of living and dead mussels at four sites; 930, E2, EC2 and C2 (Fig. 7, Fig. 8, Fig. 9, and Fig. 10 respectively). The histograms indicate high mortality in the smaller size classes except for site C2 where the dead shells of mid to large size (> 12 mm) *Dreissena* dominate. The higher number of larger dead mussel shells in the central basin may result from mortality during periodic low O₂ levels of the hypolimnion. Increased mortality of the smaller size classes may be due to competition for space and food between the newly settled mussels and the established population.

1992-1998 DISTRIBUTIONS

There was a significant increase ($p < 0.05$) in quagga mussel density over time at the 16 matched sites sampled between 1992 and 1998. Zebra mussel density declined ($p < 0.001$) over this time span in the eastern and central basins (Table 7). For all of Lake Erie the mean

zebra mussel density had declined from 3114 m⁻² to 2 m⁻² while the quagga mussel density had increased from 886 m⁻² to 5729 m⁻² (Table 8). While there had not been a significant change in either combined *Dreissena* biomass or combined density over the time period, an interaction effect was detected when comparing year and basin effects to combined *Dreissena* density ($p < 0.001$) and biomass ($p < 0.01$). The interaction effect results from the combined densities ($p < 0.01$) and biomass ($p < 0.001$) being significantly different in the basins. Interaction was greatest in the eastern basin followed by the central and then western basin.

1992-1998 Length-Frequency Distributions

Length-frequency histograms (Figs. 11-16) indicate a trend to increased average valve lengths over time. In June 1993 over 72% of the mussels were less than 7 mm compared to less than 32% in this size range during 1998. In 1993, *Dreissena* had been in eastern Lake Erie for only 5 years (1989-1993), with a young, still expanding, population. Mussels larger than 15 mm were more common in 1998 with over 28% in this size range, as contrasted to less than 7% in 1993. This suggests either an ageing population with low juvenile survival, or poor recruitment in 1997-1998 compared to that in 1993.

SHOAL COMPARISONS

No zebra mussels (*D. polymorpha*) were found at Nanticoke shoal in eastern Lake Erie during August 1998, all the *Dreissena* present were quagga mussels (*D. bugensis*). At Sunken Chicken shoal in western Lake Erie, quagga mussels averaged 7.5 % of the total *Dreissena* present at 2 m depth. Both shoals had similar sized limestone cobble (15 - 45 cm diameter), however there was more sediment on the rocks from Sunken Chicken than at Nanticoke shoal.

At both shoals, total *Dreissena* densities were significantly greater in shallower water ($p < 0.001$), whereas the biomass was greatest at the deepest site at Sunken Chicken shoal ($p < 0.001$) and to a less degree at Nanticoke shoal ($p < 0.1$), (Tables 9 and 10). *Dreissena* densities and biomass were greater at equivalent depths at Nanticoke shoal as compared to Sunken Chicken shoal ($p < 0.01$ at 3 and 4 m). Recruitment at Sunken Chicken shoal was good in September 1998 based on subsamples examined for small mussels. Average density of newly settled mussels which passed through the 1 mm screen (mean shell length 1.48 mm) was 91,900 m⁻² (SE = 21,180 m⁻², $n = 12$) representing a very minor dry biomass of 18.320 g/m² (SE = 5.126 g). Recruitment of newly settled mussels (mean length 1.16 mm) was less in August at Nanticoke shoal, averaging 32,630 m⁻² (SE = 11,450 m⁻²) at 3 m and only 2320 m⁻² at 4 m depth, representing a biomass of only 5.60 and 0.17 g/m² at the respective depths.

When comparing the 1998 Sunken Chicken shoal densities to those found in 1990 and 1991 (Table 11) there has been no significant change in mussel densities over time at 2 m, but a decrease is evident at 3 m ($p < 0.01$) and 4 m ($p < 0.001$) (Table 10).

Shoal Length-Frequency Distributions

The size distributions of the mussels collected at the shoals in 1998 were similar at the Sunken Chicken and Nanticoke shoal (Figs. 17 and 18). The length-frequency plots for Sunken Chicken shoal mussels at 3 m in 1990, 1991 and 1998 (Figs. 19 and 20) indicates an increase in mean mussel valve length. Mussels with shells greater than 10 mm represented 15%, 20% and 34% of the distribution in 1990, 1991 and 1998 respectively. However, large mussels

between 23 and 29 mm length, which were present in 1990, were absent in 1998. Biomass calculated from the size distributions and density at 3m on Chicken Shoal in 1990 and in 1991 indicated a decrease in total biomass between 1990 and 1991 (Fig. 21). However there was no difference between *Dreissena* biomass at Sunken Chicken shoal between 1991 and 1998, or between that at Nanticoke shoal in the eastern basin.

DISCUSSION

Dreissena mussels are very successful filter feeders, having a gill as retentive as any bivalve and more retentive than most (Lei et al. 1996). In high densities *Dreissena* mussels can remove large quantities of phytoplankton and suspended particulate matter from the water column (Reeders et al. 1989; Fanslow et al. 1995) and deposit agglomerations of this material and mucus as faeces and pseudofeces. The combination of high filtering capacity, high consumption and high population density bolsters the view that *Dreissena* mussels significantly alter energy flow in phytoplankton - based food web communities (Stoeckmann and Garton 1997).

The results of this study indicate there has been a slight increase in the combined *Dreissena* spp. densities and biomass in Lake Erie over the 1992 to 1998 time period. The length-frequency plots indicate a change in the population size structure of *Dreissena* mussels in Lake Erie with the trend towards increased valve lengths. This is probably due to an increasing age of the mussel population, so that a greater proportion of the population was >15 mm. In the early years of the colonization of Lake Erie (1989-1992) the rapidly expanding population consisted of younger and smaller mussels. While their impact on the aquatic ecosystem is assumed to be density-dependent (Griffiths 1993) length-frequency distributions impact the biomass, filtering stability, pseudofeces production and population stability (Deutschman 1993).

In spite of the reduced algal biomass in the shallow regions of Lake Erie (Holland 1993, Makarewicz et al 1999) *Dreissena* biomass has not been reduced at Sunken Chicken shoal in the western basin or on a lake wide basis on the soft sediments. The ageing population of larger mussels would increase the filtering capacity of the population, putting increased demands on the algae production in the lake.

The abundance of quagga mussels still shows the east to west gradient, with the highest densities in the eastern basin (Mills et al. 1993). In the eastern and central basins quagga mussel density have increased over the 1992-1998 time period while the zebra mussel densities have declined so that now zebra mussels are very rare in most of eastern Lake Erie. This may be due in part to the quagga mussel's ability to thrive and reproduce in deeper waters (Roe and MacIsaac 1997) and its ability to colonize the abundant sandy and muddy substrates in Lake Erie (Dermott and Munawar 1993). It is likely that different environmental tolerances, and growth efficiencies at lower temperatures, account for the quagga mussel's replacement of the zebra mussels in the central and eastern basins of Lake Erie. Paradoxically Domm et al. (1993) found that zebra mussels have a higher upper lethal temperature, and survival times at a constant lethal temperature were longer when compared to quagga mussels. This is consistent with May and Marsden's (1992) assertion that quagga mussels have a significantly lower level of heterozygosity relative to zebra mussels, thereby having a much narrower genetic base for different environmental responses to the environment. However, the temperature advantage of zebra mussels is marginal, as they were able to compete with quagga mussels

only in the shallowest parts of Inner Long Point Bay, often associated with submerged macrophytes on which the zebra mussels were attached.

Mussel densities were similar at all depths except in the 5-10 m range where the density was approximately twice that at the other ranges. Presumably environmental (temperature and substrate) and ecological (food supply) are most favourable in this upper depth range. The biomass was greatest in the 20-30 m depth range, a large part of which is accounted for by larger average mussel size at that depth. During the winter, ice scour and winter storm surges result in a high over winter mortality in mussel populations in shallow water (Chase and Bailey 1999). As a result populations in the shallow Inner Long Point Bay consisted primarily of new recruits growing on the aquatic macrophytes. Mussels below 10-20 m are immune from the detrimental effects of ice and winter storms, living longer and growing larger, with mortality rates perhaps as low as 2.5%. The increased mortality rates of the larger mussels in the central basin (25-51%) may be due to periods of low O₂ in the hypolimnion of the central basin.

Since 1993 the percentage of zebra mussels has significantly dropped throughout Lake Erie, the zebra mussels being replaced by the quagga mussel. As total *Dreissena* biomass on the western rocky shoals has stayed similar to that in 1991, the impact of their filtration on the algal and zooplankton community remains. However the greatest impact on the lake community is occurring in the central and eastern basins where *Dreissena* biomass has increased since 1993, and density is more similar at all sites and depths.

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Table 1. Lake Erie site identification and locations for 1998. DFO site number in brackets.

Site Number	Depth (m)	Latitude	Longitude
930	58.5	42° 28.95'	80° 02.80'
933	15.9	42° 49.00	79° 34.08
934	28.0	42° 42.52	79° 30.47
E1	5.5	42° 46.77	80° 08.70
E2 (938)	38.0&40.0	42° 37.58	80° 03.27
E3 (937)	9.0	42° 42.82	80° 13.77
E4 (939)	57.0	42° 34.00	79° 55.00
E5	2.6	42° 37.27	80° 21.50
E10	2.8	42° 37.50	82° 21.00
J11	2.0	42° 38.60	80° 23.30
M29	46.0	42° 32.60	80° 91.40
N27	7.0	42° 38.00	80° 16.90
940	48.0	42° 26.48	79° 50.08
942	16.0	42° 15.55	79° 49.90
EC1 (943)	12.1	42° 34.43	81° 38.53
944	17.5	42° 31.90	80° 38.42
EC2 (945)	21.9	42° 24.00	80° 38.62
C1 (950)	9.1	42° 35.25	81° 26.50
C2 (952)	22.3	42° 21.52	81° 26.57
954	24.2	42° 01.50	81° 26.62
956	11.0	41° 41.33	81° 26.93
WC1	16.8	42° 04.60	82° 20.40
WC3	22.3	41° 59.00	82° 08.40
967	12.0	41° 53.50	82° 39.98
W3 (970)	10.7	41° 49.57	82° 58.55
971	9.5	41° 56.87	83° 03.02
W5	11.7	41° 53.00	82° 36.80
W6	12.5	41° 51.25	82° 45.80
W7	10.3	41° 59.50	82° 45.80
W8	10.3	41° 59.20	82° 34.50
Sunken Chicken shoal		41° 46.33	82° 47.44
Nanticoke shoal		42° 44.24'	80° 04.00'

Table 2. Lake Erie 1998. *Dreissena* density (no./m²) and biomass (g/m² wet weight with the shell) measurements for 1mm mesh portion.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density	Biomass	Density	Biomass	Density	Biomass
930	58.5	1	3780	463.4	3780	463.4	0	0
		2	7650	766.7	7650	766.7	0	0
		mean	5715	615.1				
933	15.9	1	7650	1065.0	7650	1065.0	0	0
		2	3600	365.6	3600	365.6	0	0
		3	4095	458.4	4095	458.4	0	0
		4	3645	268.4	3645	268.4	0	0
		mean	4748	539.4				
934	28.0	1	2205	604.3	2205	604.3	0	0
		2	675	315.8	675	315.8	0	0
		3	765	521.1	765	521.1	0	0
		mean	1215	480.4				
E1	5.5	1	113.4	11.4	113.4	11.4	0	0
		2	56.7	10.4	56.7	10.4	0	0
		3	0	0	0	0	0	0
		mean	57	7.3				
E2	38.0	1	4095	1171.8	4095	1171.8	0	0
		2	2160	551.9	2160	551.9	0	0
	40.0	1	810	136.0	810	136.0	0	0
		2	3375	916.8	3375	916.8	0	0
		mean	2610	694.1				
E3	9.0	1	26010	2492.5	26010	2492.5	0	0
		2	36405	3219.2	36405	3219.2	0	0
		mean	31208	2855.9				
E4	57.0	1	9810	1394.5	9810	1394.5	0	0
		2	2700	380.9	2700	380.9	0	0
		mean	6255	887.7				
E5	2.6	1	660	47.1	40	2.7	620	44.3
		2	1340	115.4	60	7.1	1280	108.3
		3	2100	189.6	160	15.4	1940	174.3
		4	2040	143.8	0	0	2040	143.8
		mean	1535	124.0				
E10	2.8	1	1260	77.3	990	36.4	270	41.0
		2	1575	45.7	1485	40.5	90	5.2
		3	990	74.0	765	37.3	225	36.7
		4	1170	45.7	945	23.6	225	22.1
		5	3510	117.2	2970	28.9	540	88.4
		mean	2126	72.0				

Table 2. Continued. Lake Erie 1998.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density	Biomass	Density	Biomass	Density	Biomass
J11	2.0	1	16830	1508.9	0	0	16830	1508.9
		2	1755	91.5	0	0	1755	91.5
		3	3150	236.0	270	1.9	2880	234.1
		4	1665	90.9	0	0	1665	90.9
		mean	5850	481.8				
M29	46.0	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		mean	0	0				
N27	7.0	1	3060	103.6	3060	103.6	0	0
		2	1710	61.9	1710	61.9	0	0
		3	1755	54.6	1755	54.6	0	0
		mean	2175	73.4				
940	48.0	1	3690	724.0	3690	724.0	0	0
942	16.0	1	19080	2263.0	19080	2263.0	0	0
		2	15750	2747.92	15750	2747.9	0	0
		mean	17415	2505.4				
EC1	12.1	1	360	1.1	360	1.1	0	0
		2	630	14.8	630	14.8	0	0
		mean	495	7.9				
944	17.5	1	0	0	0	0	0	0
		2	16425	1959.3	16425	1959.3	0	0
		mean	8212	979.6				
EC2	21.9	1	45	10.0	45	10.0	0	0
		2	3960	584.3	3960	584.3	0	0
		mean	2002	297.2				
C1	9.1	1	7785	149.3	7785	149.3	0	0
		2	135	0.4	135	0.4	0	0
		mean	3960	74.9				
C2	22.3	1	16740	9448.3	16740	9448.3	0	0
		2	45	0.08	45	0.08	0	0
		3	10800	3147.4	10800	3147.4	0	0
		4	5805	913.9	5805	913.9	0	0
		mean	8348	3377.4				
954	24.2	1	135	44.1	135	44.1	0	0
956	11.0	1	315	1.9	315	1.9	0	0
		2	135	6.8	135	6.8	0	0
		mean	225	4.4				

Table 2. Continued. Lake Erie 1998.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density	Biomass	Density	Biomass	Density	Biomass
WC1	16.8	1	5625	60.8	5625	60.8	0	0
		2	900	336.4	855	15.2	45	321.1
		mean	3262	198.6				
WC3	22.3	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
967	12.0	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
W3	10.7	1	0	0	0	0	0	0
		2	135	42.6	45	37.5	90	4.9
		mean	68	21.3				
971	9.5	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
W5	11.7	1	5220	2537.6	1845	1224.0	3375	1313.6
		2	495	257.2	270	151.6	225	105.6
		mean	2858	1397.4				
W6	12.5	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
W7	10.3	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
W8	10.3	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				

Table 3. Average *Dreissena* density (no./m²) and biomass (g/m² wet weight with shell) by basin in Lake Erie at all 30 sites sampled in 1998, n = number of replicates.

Basin	n	Combined <i>Dreissena</i> Density	SE	Zebra Mussel Density	SE	Quagga Mussel Density	SE
Eastern	42	4826	1158	723	407	4103	1147
Central	19	3676	1272	2	2	3673	1272
Western	14	418	371	264	240	154	131

Basin	n	Combined <i>Dreissena</i> Biomass	SE	Zebra Mussel Biomass	SE	Quagga Mussel Biomass	SE
Eastern	42	568	124	62	36	506	125
Central	19	878	512	17	17	861	513
Western	14	203	181	102	94	101	87

Table 4. Lake Erie 1998. Average *Dreissena* density (no./m²) and biomass (g/m² wet weight with shell) by depth, n = number of replicates from 30 sites.

Depth (m)	n	Comb. <i>Dreissena</i> Density	SE	Zebra Mussel Density	SE	Quagga Mussel Density	SE
0-5	13	2927	1180	2335	1232	591	241
5-10	12	6419	3463	0	-	6419	3463
10-20	26	3233	1090	143	130	3089	1090
20-30	12	3431	1535	0	-	3431	1535
30+	12	3172	882	0	-	3172	882
All Depths Combined	75	3712	746	455	234	3257	734

Depth (m)	n	Comb. <i>Dreissena</i> Biomass	SE	Zebra Mussel Biomass	SE	Quagga Mussel Biomass	SE
0-5	13	214	109	199	111	15	4
5-10	12	509	320	0	-	509	320
10-20	26	476	170	0	-	476	170
20-30	12	1299	783	0	-	1299	783
30+	12	542	136	0	-	542	136
All Depths Combined	75	578	151	58	27	520	149

Table 5. Lake Erie 1998. Average Valve lengths (mm), average filtering rates (ml/hr/mussel) and calculated filtration rates (ml/hr/m²) per site based on the combined *Dreissena* density (no./m²), n = number of shells measured.

Quagga mussels							
Site #	Depth (m)	n	Mean Valve Length (mm)	SE of the length	Filtering Rate (ml/hr/mussel)	Density (no./m ²)	Filtration Rate (ml/hr/m ²)
930	58.5	84	8.91	0.49	6.76	5715	38633
933	15.9	91	8.59	0.46	6.09	4748	28915
934	28.0	64	15.76	0.46	33.98	1215	41286
E2	38.0	231	13.86	0.35	25.02	2610	65302
E3	9.0	213	8.57	0.26	6.05	31208	188808
E4	57.0	60	9.58	0.73	8.34	6255	52167
E10	2.8	159	5.46	0.20	2.10	2126	5528
N27	7.0	107	5.88	0.32	2.43	2175	5285
940	48.0	82	12.63	0.66	19.26	3690	71069
942	16.0	107	11.90	0.28	16.12	17415	280730
EC1	12.1	22	3.99	0.58	1.24	495	614
944	17.5	142	9.60	0.40	8.39	8212	68899
EC2	21.9	89	9.75	0.57	8.79	2002	17598
C1	9.1	60	4.86	0.60	1.70	3960	6732
C2	22.3	155	14.83	0.83	29.69	8348	247852
WC1	16.8	125	4.69	0.13	1.60	3262	5219
W5	11.7	47	18.48	0.52	43.79	1057	46308
Zebra mussels							
E5	2.6	192	8.80	0.16	6.52	1535	10407
E10	2.8	30	10.20	0.70	10.07	2126	5528
J11	2.0	507	9.33	0.085	7.72	5850	45162
W5	11.7	80	14.81	0.46	29.59	1800	53262

Table 6. Lake Erie 1998. Estimated mortality rate in the offshore zone. Live and dead mussels are the average of the combined zebra and quagga mussels per mini PONAR sample, n = number of replicates.

Site. #	n	Live Mussels	SE	Dead Mussels	SE	% Dead
930	2	130.5	43.5	10.8	4.8	7.6
E2	4	59.2	16.4	19.1	9.7	24.4
E4	2	140.5	77.5	6	5	4.1
940	1	83	-	2	-	2.4
Combined East Sites.	9	95.8	20.7	12.4	4.7	11.5
EC2	2	46.5	45.5	50.5	32.5	51.5
C2	4	187	80.2	63.8	35.3	25.4
954	1	3	-	3	-	50
Combined Central Sites.	7	120.6	54.3	51.3	21.8	29.8

Table 7. *Dreissena* density (no./m²) and biomass (g/m² wet weight with the shell) by basin at 16 matched sites in Lake Erie 1992, 1993, 1998. Number of sites were 6, 7 and 3 for the Eastern, Central and Western basins respectively, mean basin depths of 27.4, 16.2 and 10.6 meters respectively, n = number of replicates.

Basin	n	Total <i>Dreissena</i> Density	SE	Zebra Mussel Density	SE	Quagga Density	SE	Total Biomass	SE	Quagga Biomass	SE
<u>1992</u>											
East	11	8767	4094.7	6643.6	4278.1	2123	713.5	653.54	300.3	214.401	73.3
Central	12	1611	1231.0	1415.6	1093.6	195	143.1	295.15	216.6	72.166	63.6
West	6	38	18.1	37.5	18.1	0	0.0	2.88	1.6	0	0
<u>1993</u>											
East	65	5479	765.9	1091.8	318.6	4387	580.2	519.67	91.5	448.128	68.4
Central	26	1214	624.0	706.2	371.4	507	259.2	197.56	100.8	102.487	56.9
West	23	5037	2423.5	5037.2	2423.5	0	0.0	801.28	410.2	0	0
<u>1998</u>											
East	15	9525	2677.3	0.0	0.0	9525	2677.3	1210.39	258.0	1210.394	257.9
Central	15	4221	1558.5	0.0	0.0	4221	1558.5	1085.44	642.0	1085.441	642.0
West	6	23	22.5	15.0	15.0	8	7.5	7.10	7.1	6.25	6.3

Table 8. Lake wide average *Dreissena* densities (no./m²) and biomass (g/m²) by year, wet weight with shells at 16 matched sites in Lake Erie sampled in 1992, 1993 and 1998, n = number of replicates.

Year	n	Combined <i>Dreissena</i> Density	SE	Zebra Mussel Density	SE	Quagga Mussel Density	SE	Total Biomass	SE
1992	29	4000	1740	3114	1719	886	325	371	148
1993	114	4417	683	1800	542	2617	386	544	101
1998	36	5731	1398	2	2	5729	1398	958	292

Table 9. Estimated densities (no./m²) and biomass (g/m² dry shell on) of *Dreissena* mussels at two depths (m) at Nanticoke shoal, 1998, n = number of replicates.

Depth (m)	n	Density (no./m ²)	SE	Biomass (g/m ²)	SE
3.0	31	68 529	5 069	3 708	240
4.0	18	40 289	2 064	4 524	420

Table 10. Estimated densities (no./m²) and biomass (g/m² dry shell on) of zebra mussels at three depths (m) at Sunken Chicken shoal, 1998, n = number of replicates.

Depth (m)	n	Density (no./m ²)	SE	Biomass (g/m ²)	SE
2.0	30	68 547	6 911	1 670	317
3.0	30	48 440	4 976	3 042	326
4.0	30	29 200	2 190	4 413	326

Table 11. Estimated densities (no./m²) of zebra mussels at three depths (m) at Sunken Chicken shoal, 1990 and 1991, n = number of replicates.

Year	Depth (m)	n	Density (no./m ²)	SE
1990	1.5 (<2)	6	76 500	32 782
	3.0 (2-4)	15	135 000	19 726
	4.5 (>4)	3	344 300	81 753
1991	1.5 (<2)	16	79 900	15 425
	3.0 (2-4)	24	77 500	7 940
	4.5 (>4)	3	106 800	25 288

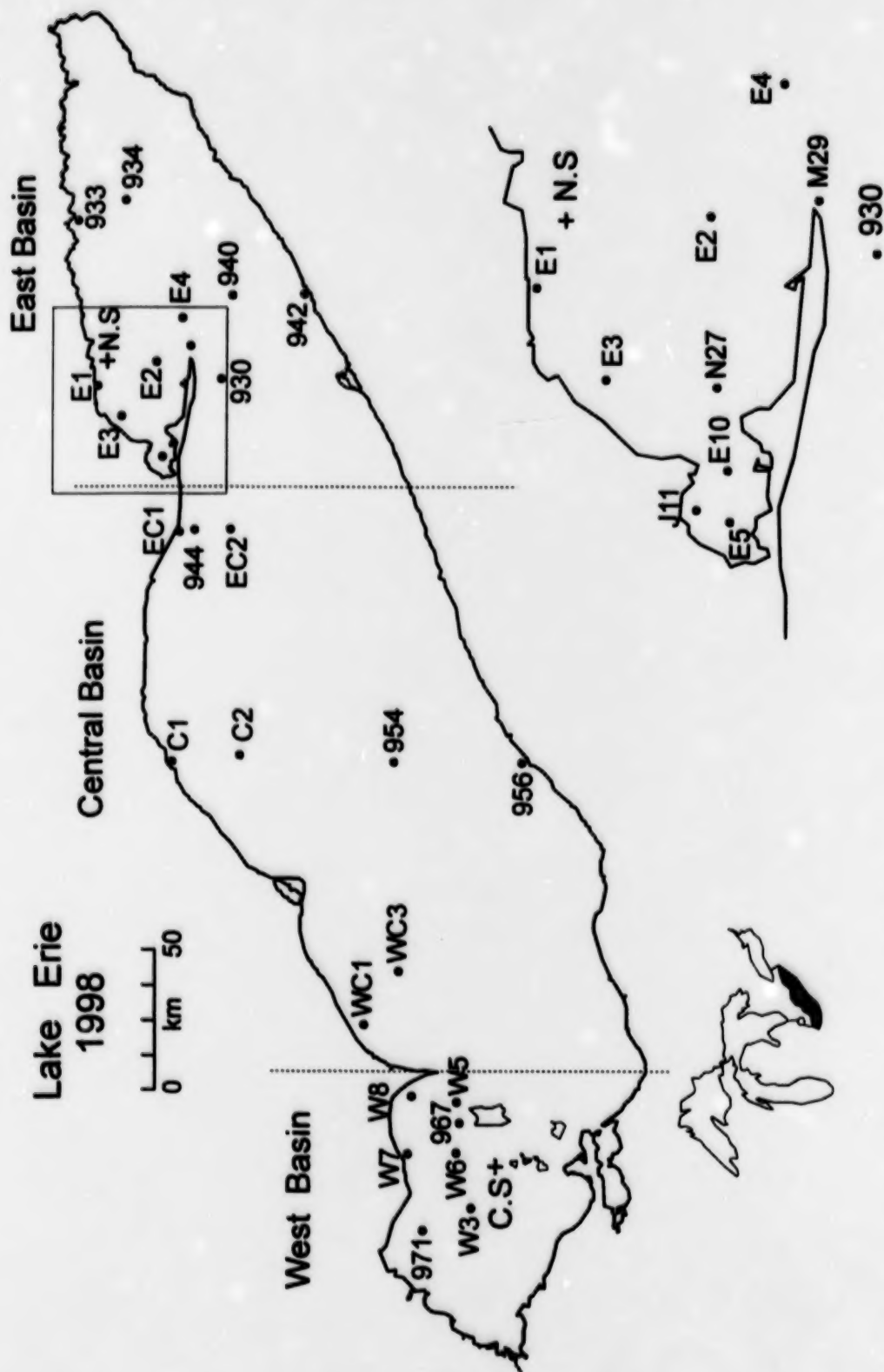


Figure 1. Lake Erie sampling sites in 1998.

Lake Erie Sites 1992 - 1993 & Depth Contours (m)

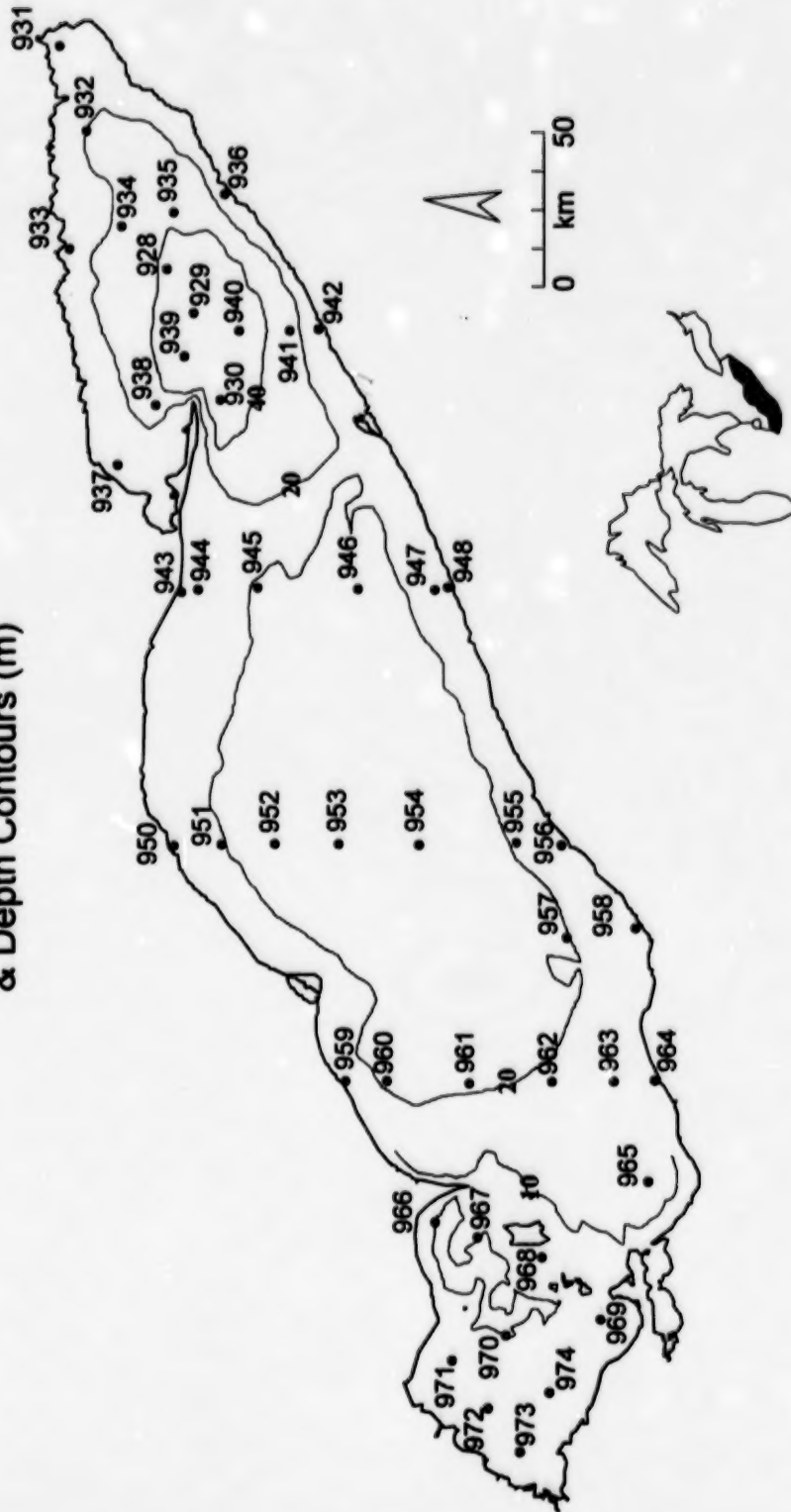


Figure 2. Lake Erie sampling sites in 1992 and 1993.

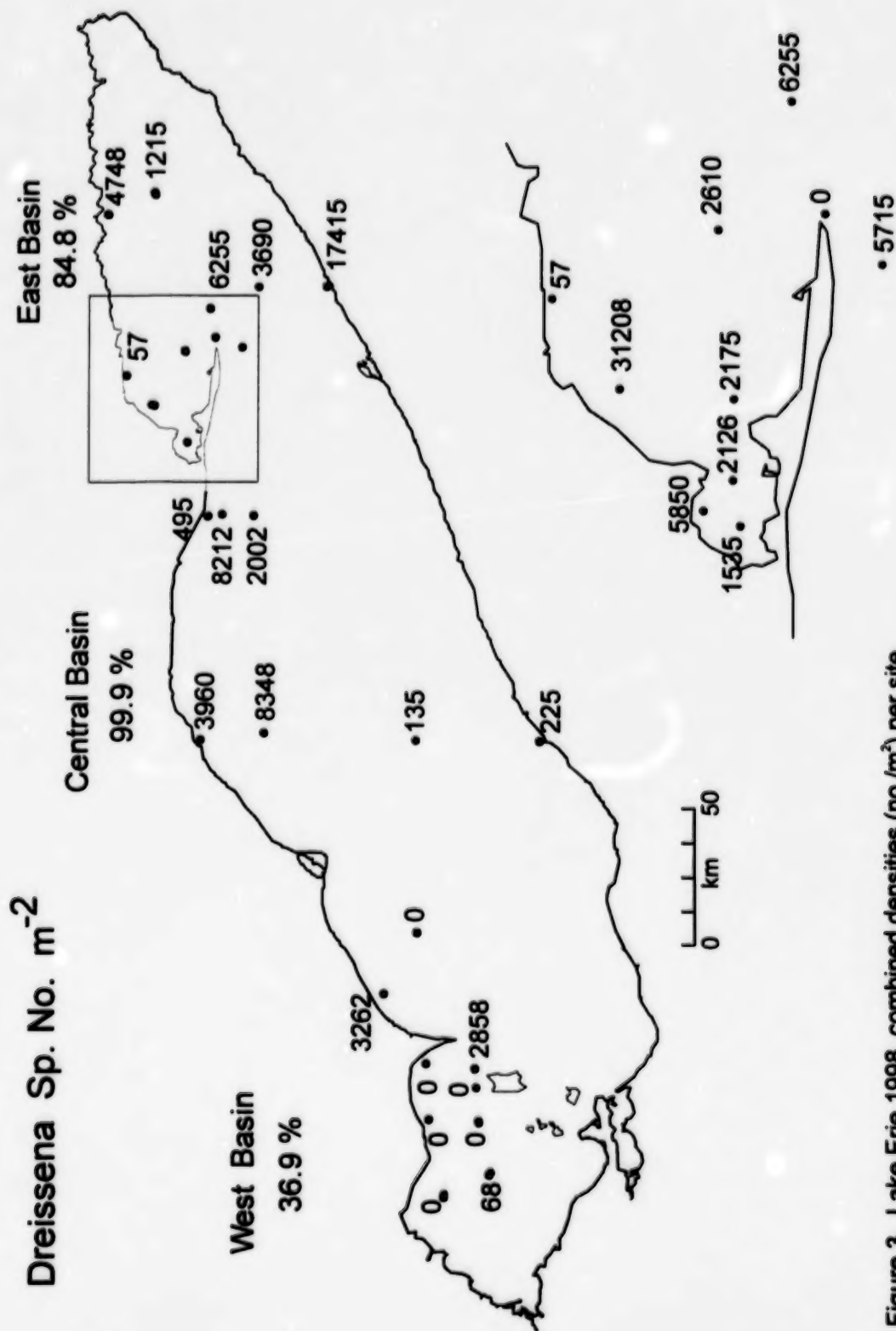


Figure 3. Lake Erie 1998, combined densities (no./m²) per site and percentage of quagga mussels per basin.

Lake Erie Basin Average Spring 1998

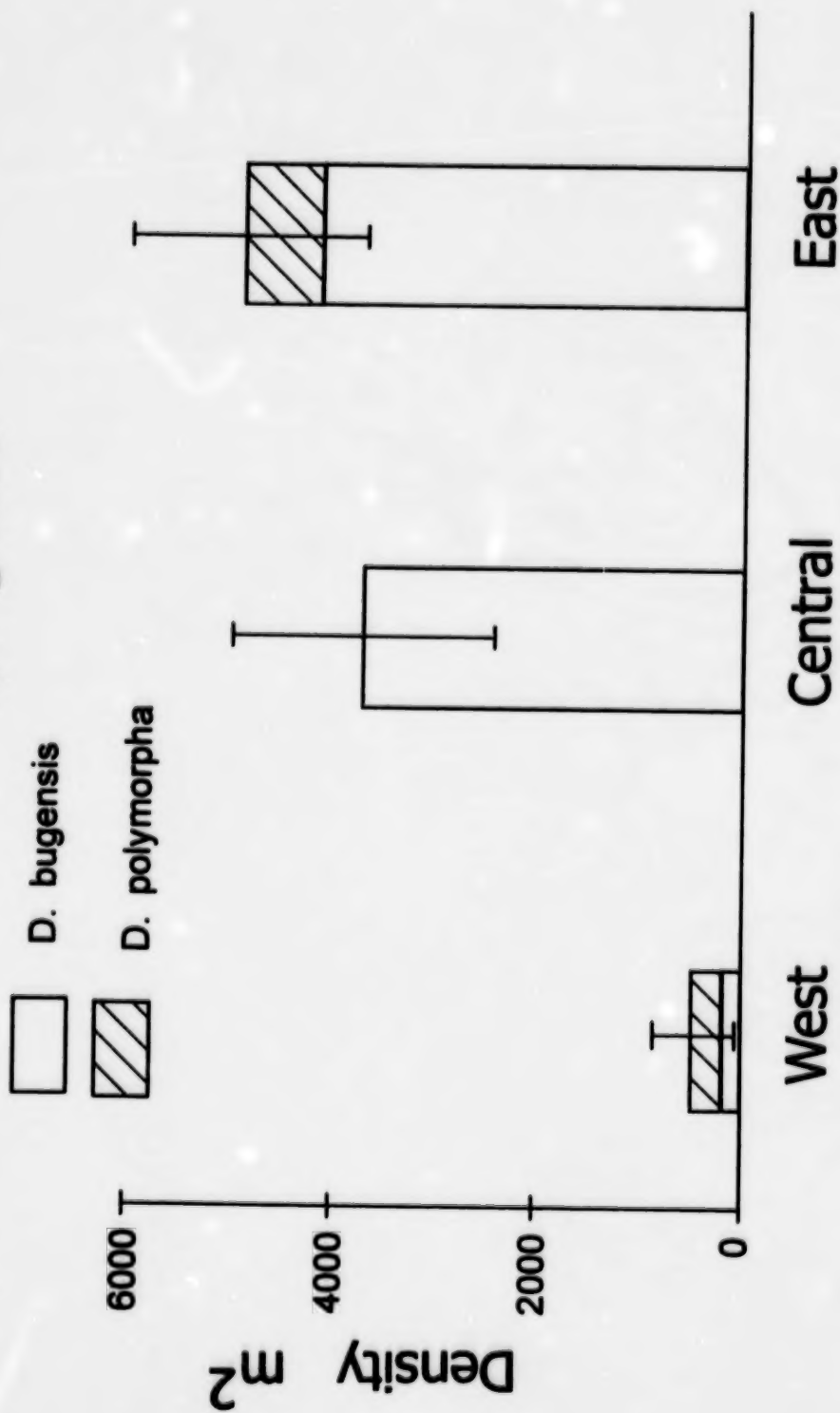


Figure 5. Average basin densities (no./m²) of *Dreissena* spp. from all sites sampled in 1998.

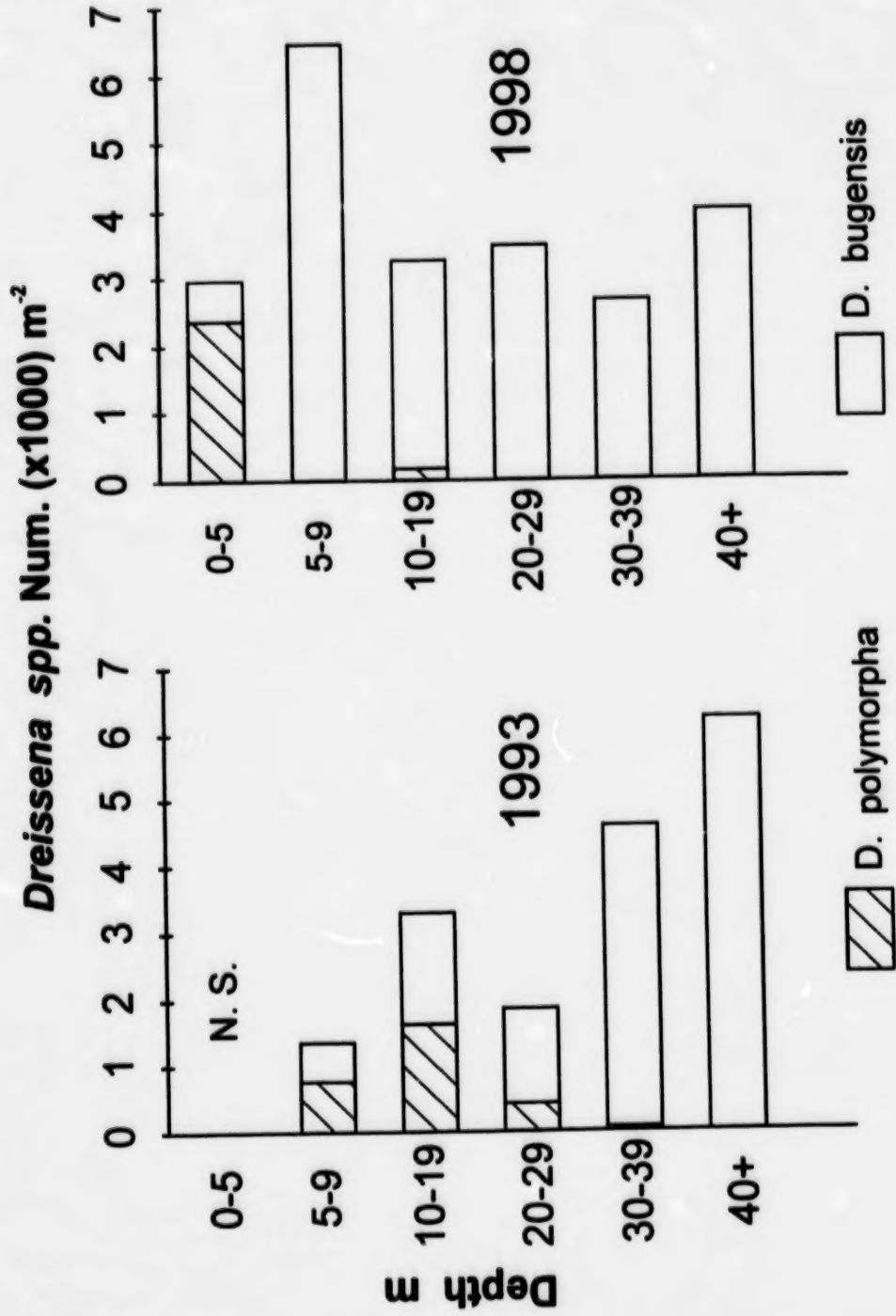


Figure 6. Density (no. x 1000/m²) of *Dreissena* spp. at various depths (m) in Lake Erie during 1993 and 1998.

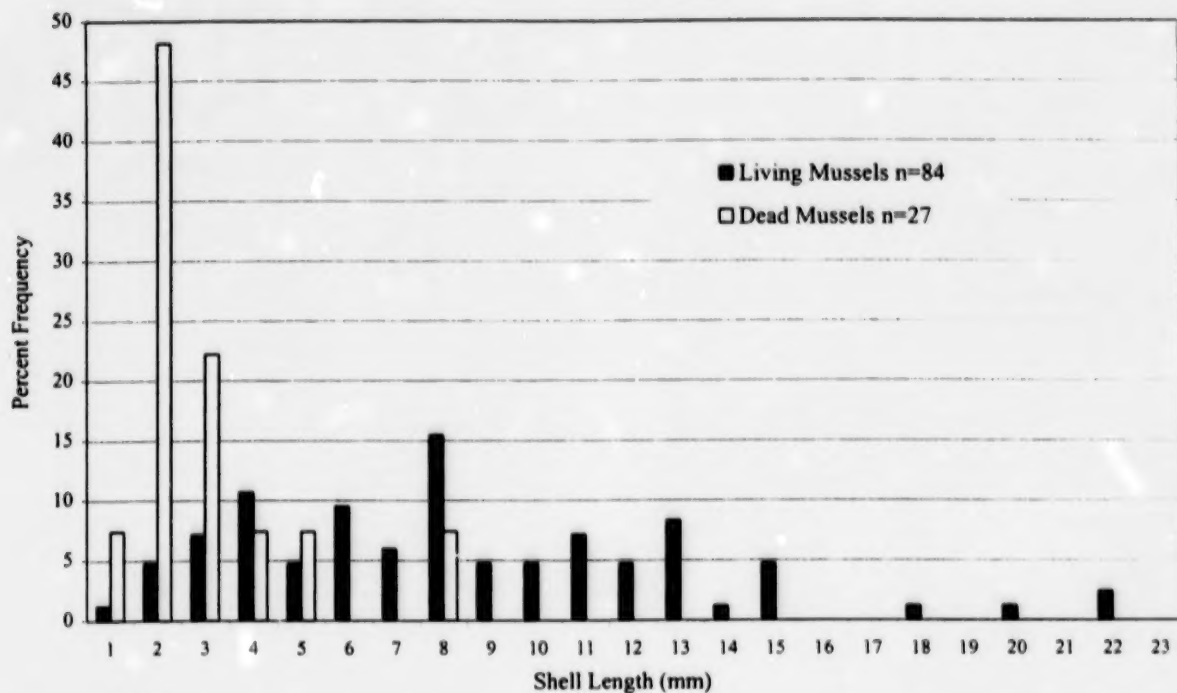


Figure 7. Length-frequency distributions of living and dead *Dreissena* mussels in 1998 at site 930.

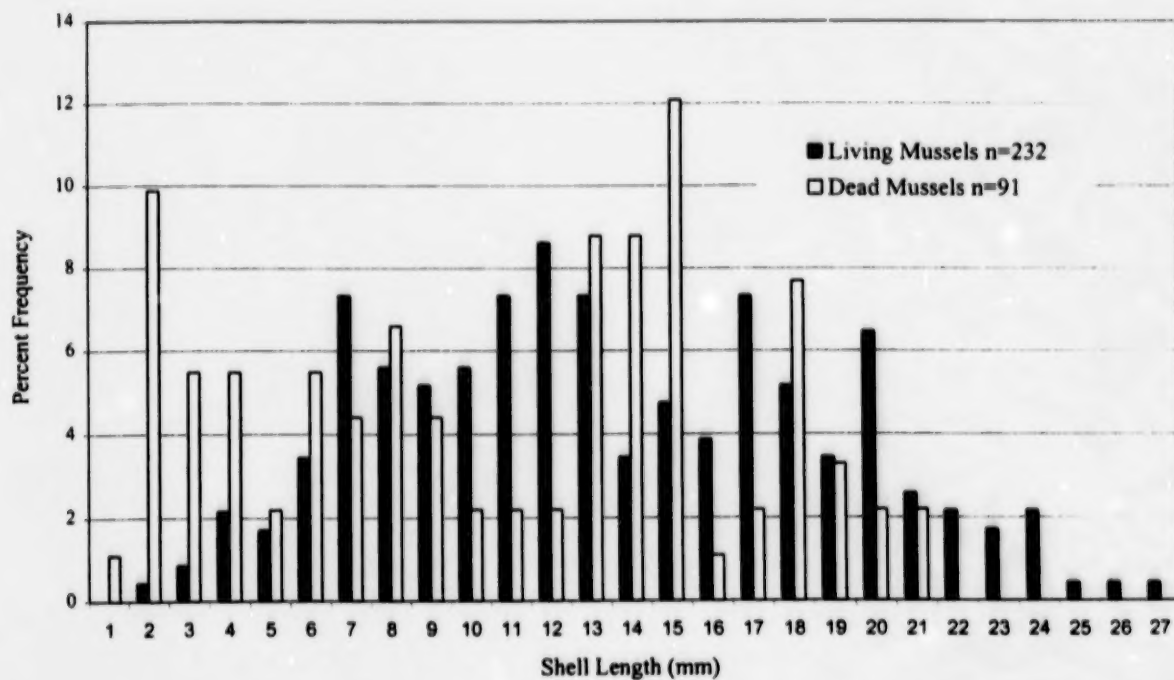


Figure 8. Length-frequency distributions of living and dead *Dreissena* mussels in 1998 at site E2.

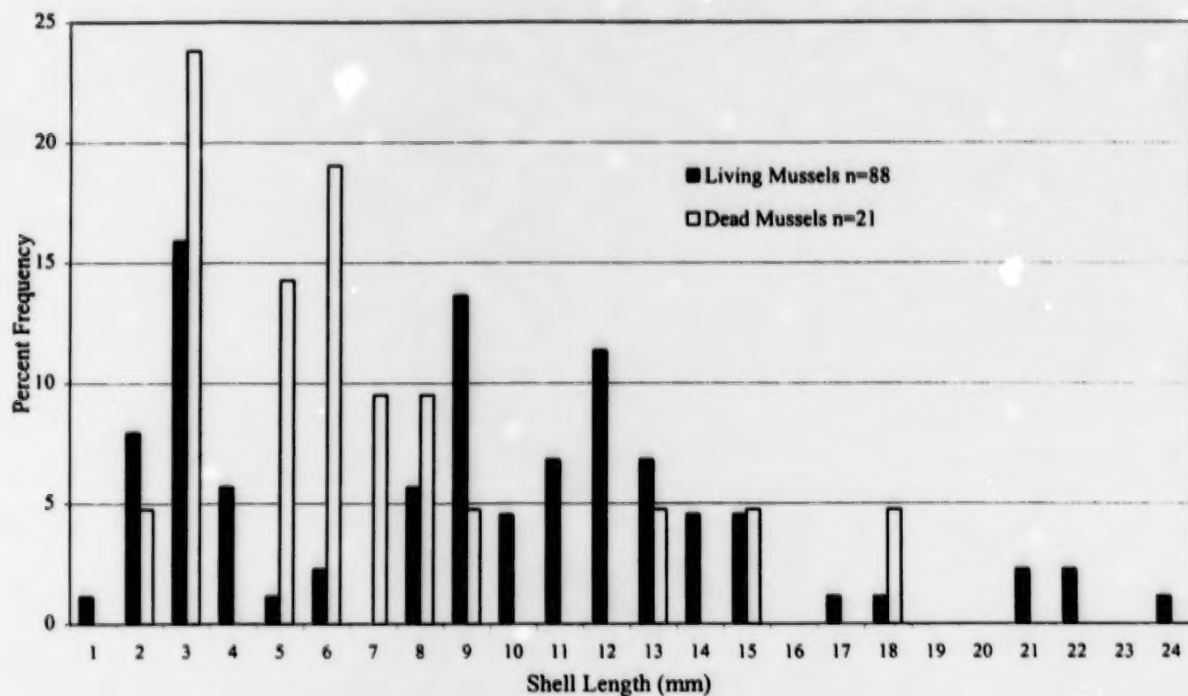


Figure 9. Length-frequency distributions of living and dead *Dreissena* mussels in 1998 at site EC2.

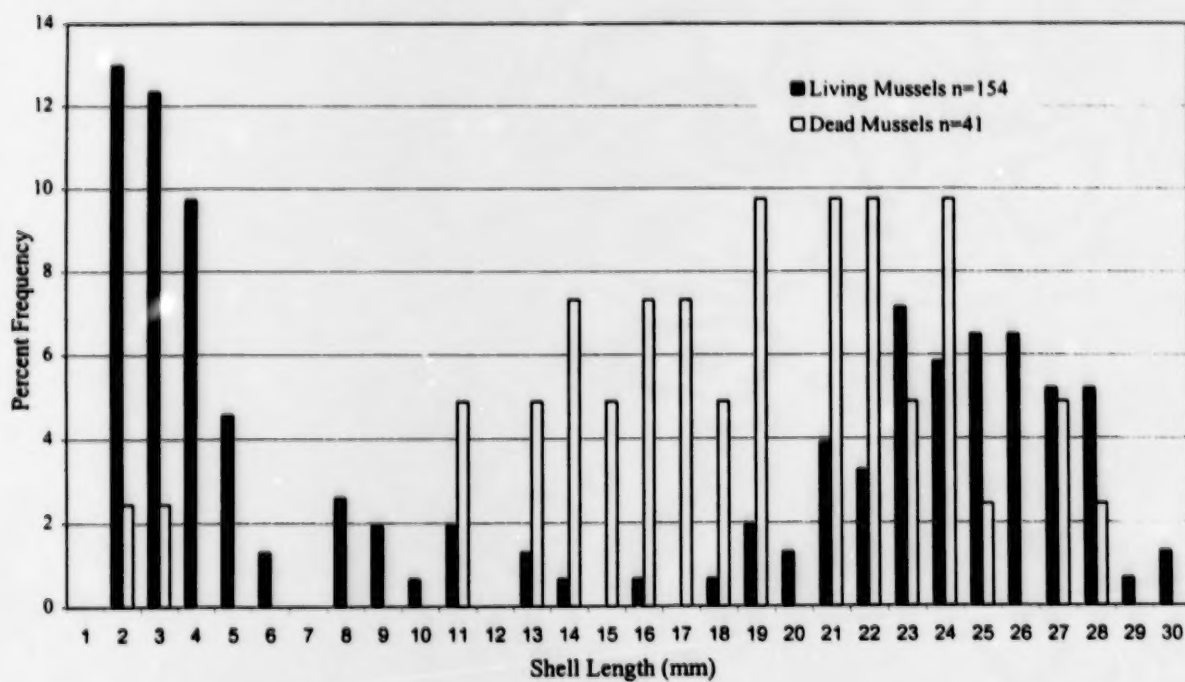


Figure 10. Length-frequency distributions of living and dead *Dreissena* mussels in 1998 at site C2.

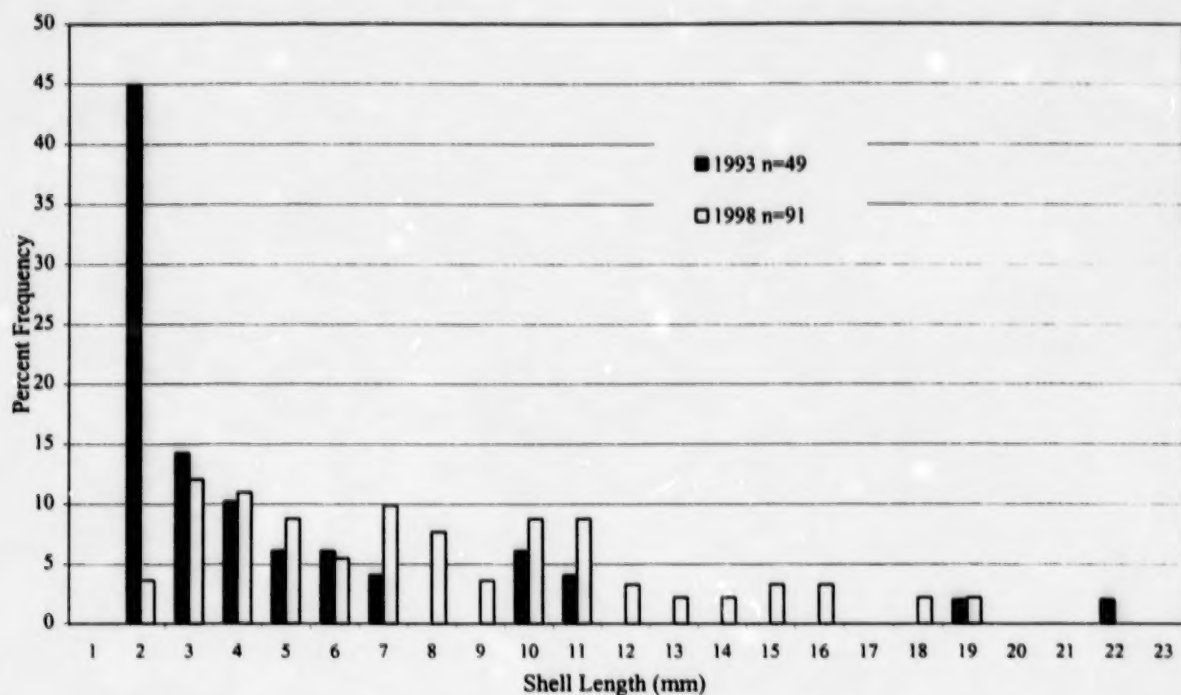


Figure 11. Length-frequency distributions of *Dreissena* mussels in 1993 and 1998 at site 933.

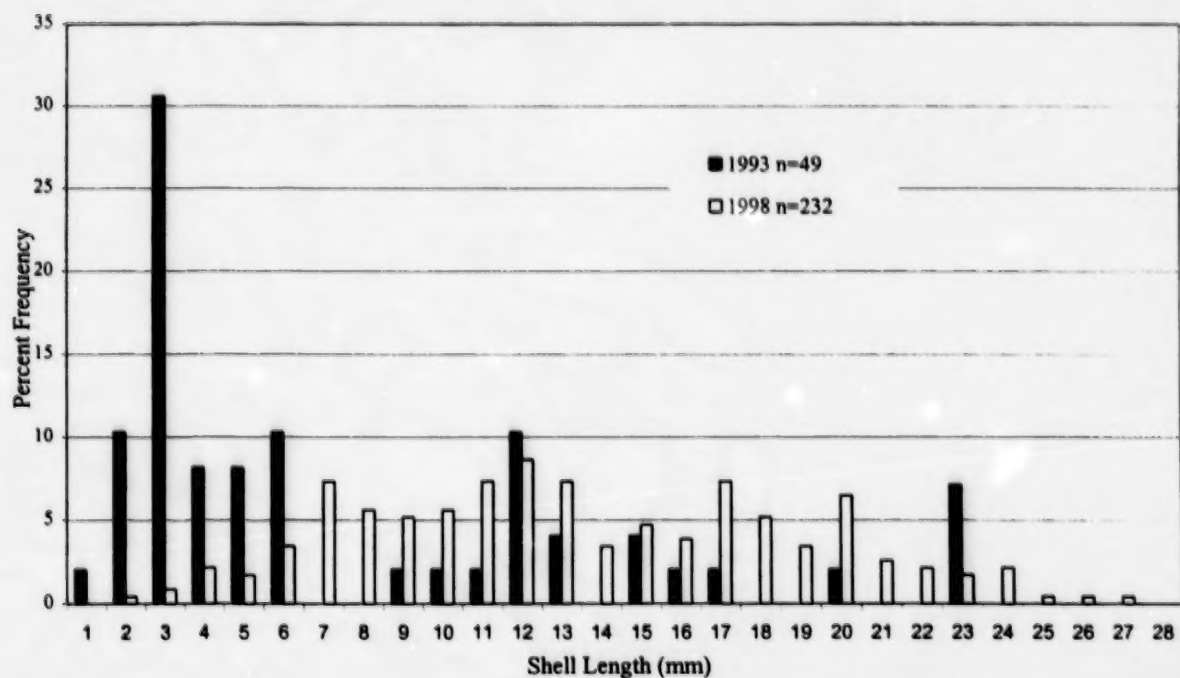


Figure 12. Length-frequency distributions of *Dreissena* mussels in 1993 and 1998 at site E2.

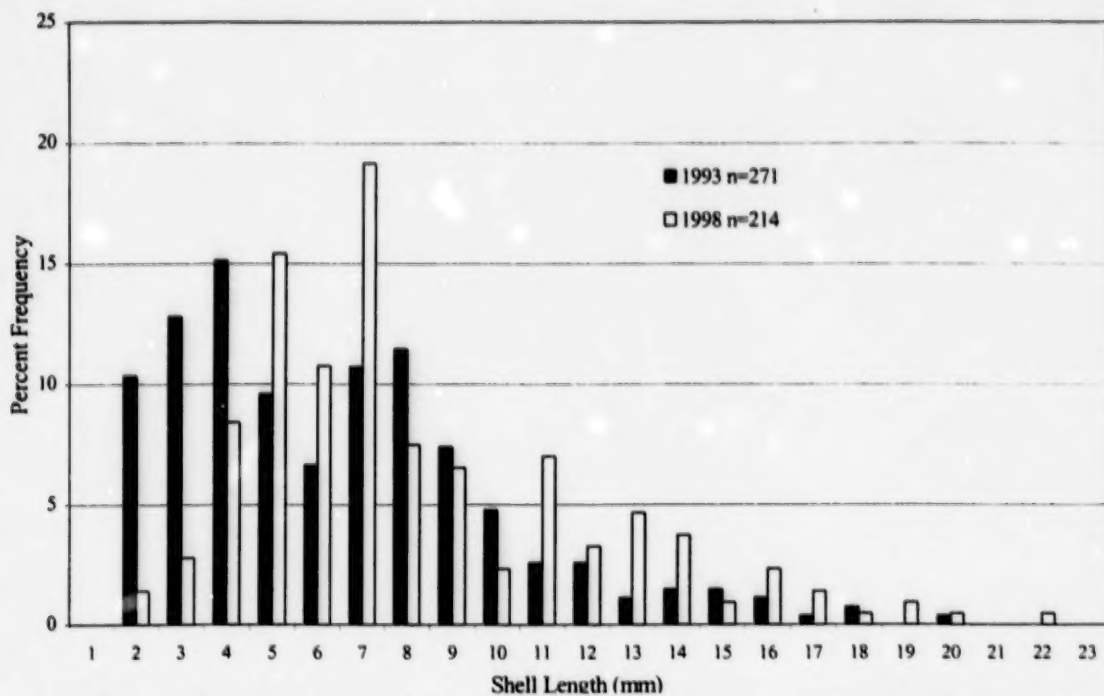


Figure 13. Length-frequency distributions of *Dreissena* mussels in 1993 and 1998 at site E3.

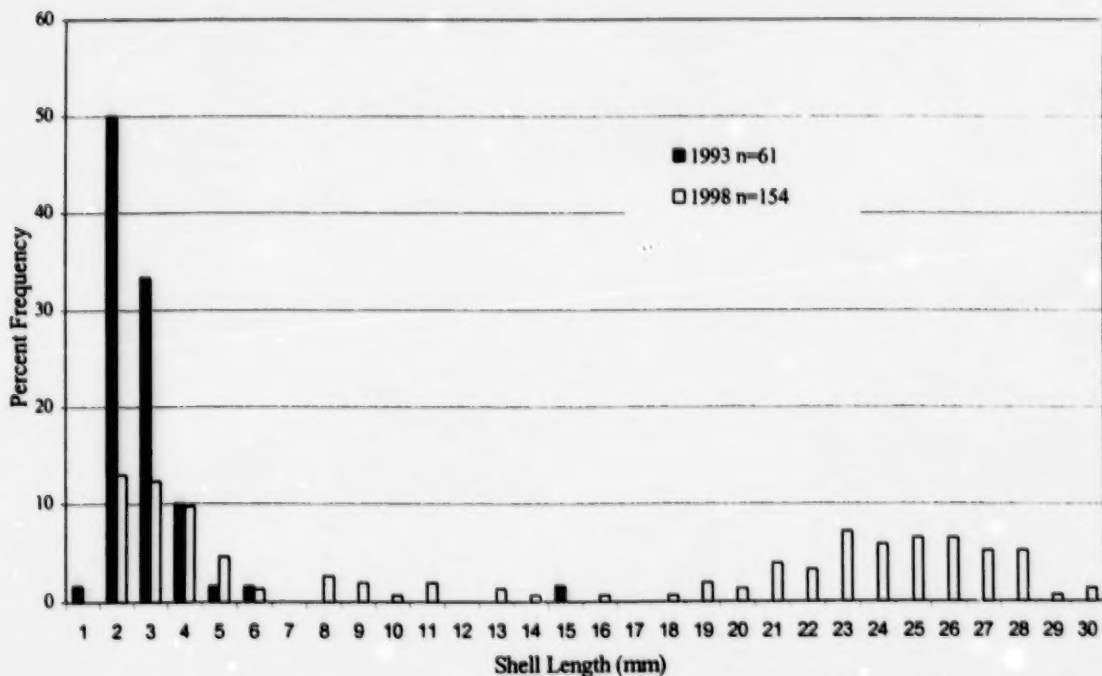


Figure 14. Length-frequency distributions of *Dreissena* mussels in 1993 at site 951 and site C2 in 1998.

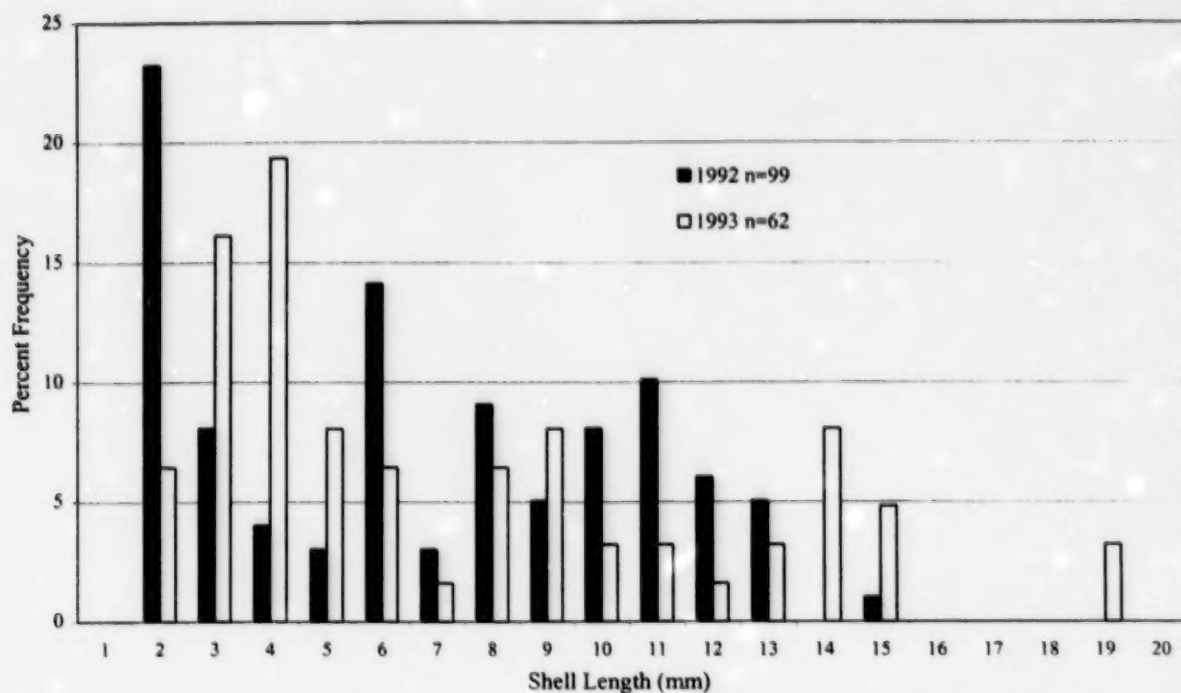


Figure 15. Length-frequency distributions of *Dreissena* mussels in 1992 and 1993 at site 940.

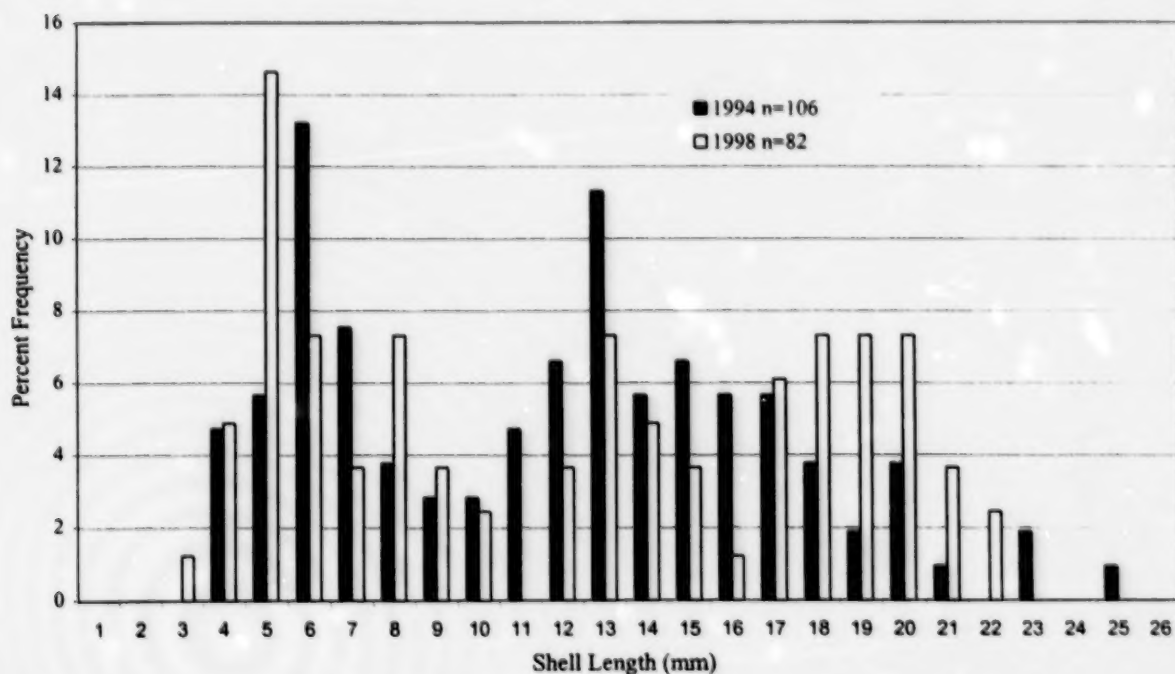


Figure 16. Length-frequency distributions of *Dreissena* mussels in 1994 and 1998 at site 940.

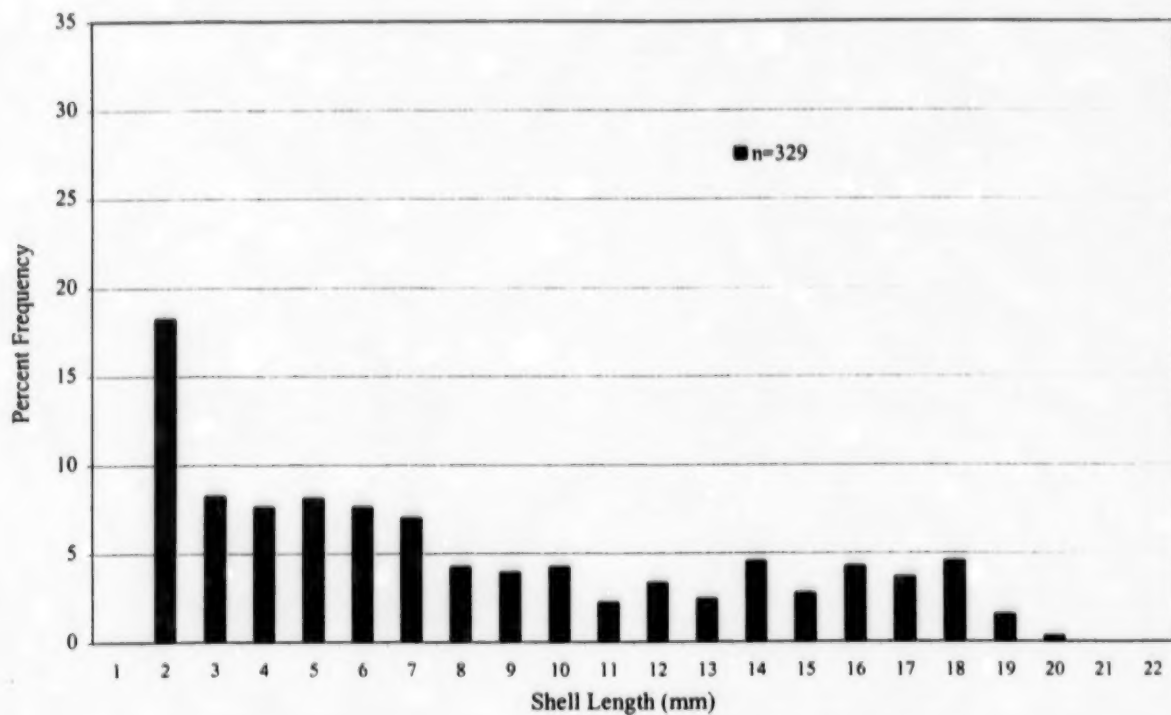


Figure 17. Length-frequency distribution of *Dreissena* mussels at Nanticoke shoal (3m) in 1998.

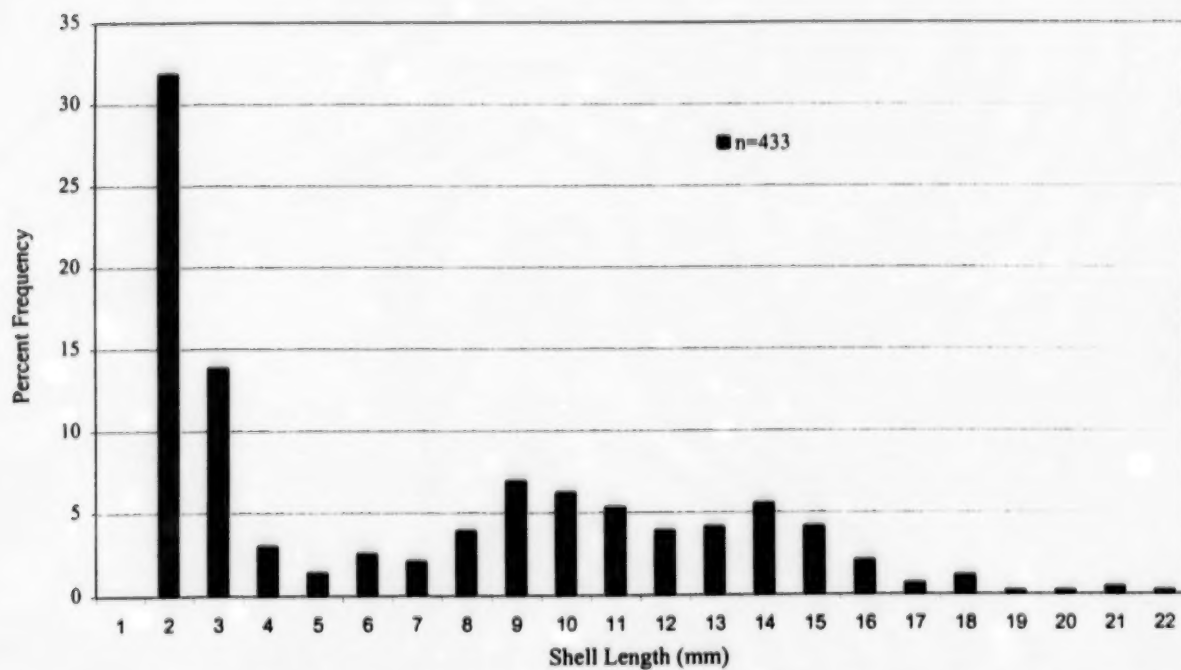


Figure 18. Length-frequency distribution of *Dreissena* mussels at Sunken Chicken shoal (3m) in 1998.

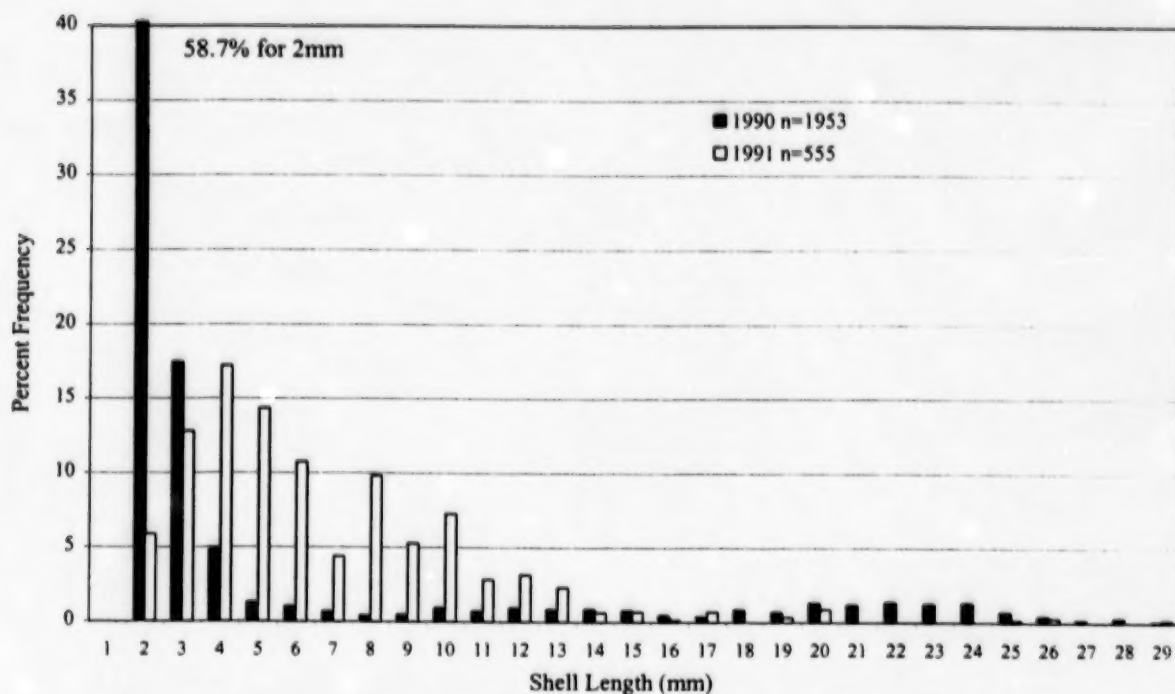


Figure 19. Length-frequency distribution of *Dreissena* mussels at Sunken Chicken shoal (3m) in 1990 and 1991. Data from Fitzsimons et al. 1995.

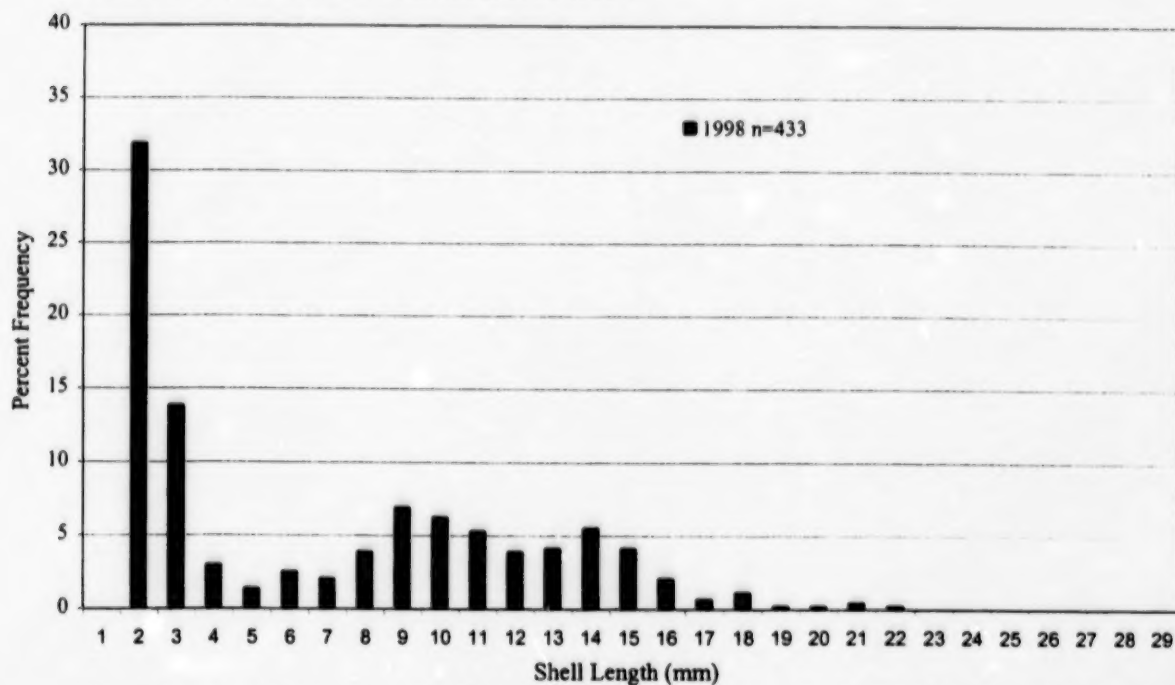


Figure 20. Length-frequency distribution of *Dreissena* mussels at Sunken Chicken shoal (3m) in 1998.

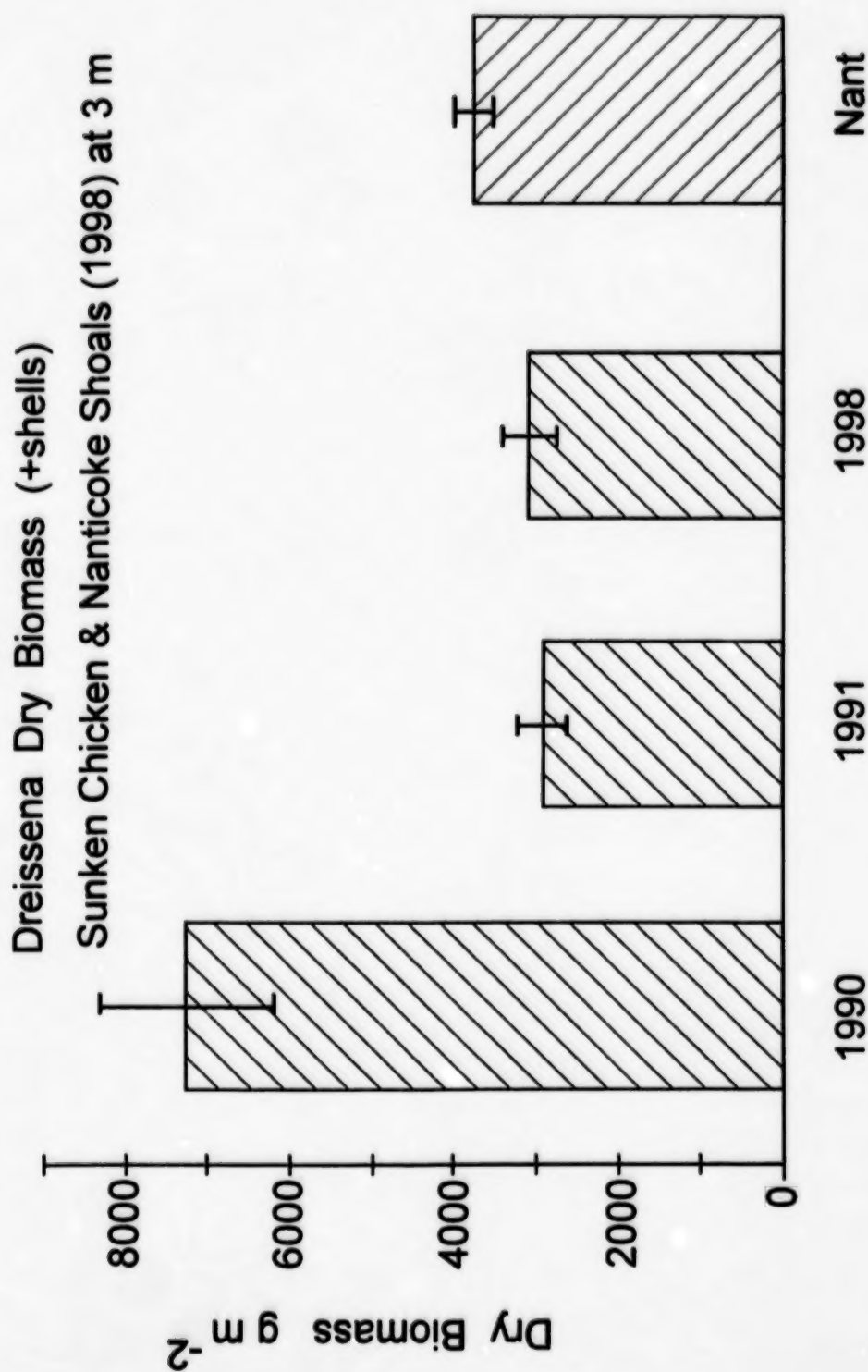


Figure 21. *Dreissena* biomass (g/m^2) at 3 m on Sunken Chicken Shoal in 1990, 1991 and 1998, and at Nanticoke Shoals in 1998, dry weight with shell.

Appendix 1. Lake Erie 1992. *Dreissena* density (no./m²) and biomass (wet weight with the shell g/m²) measurements for 1mm mesh portion. All data from the 1992 survey is included in this appendix while only sites matching 1993 and 1998 were used in the statistical analysis. * indicates the *Dreissena* mussels were not separated into zebra and quagga mussels thereby only combined *Dreissena* data is available.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
928	58.0	1	855	10.8	855	10.8	0	0
		2	855	17.6	855	17.6	0	0
		mean	855	14.2				
929	63.0	1	2250	62.0	2250	62.0	0	0
		2	1260	31.4	1260	31.4	0	0
		mean	1755	46.7				
930	58.0	1	90	2.4	90	2.4	0	0
		2	90	0.05	90	0.05	0	0
		mean	90	1.2				
931	8.5	1	12870	1051.0	0	0	12870	1051.0
932	21.3	1	630	72.1	45	*	585	*
		2	1485	170.0	180	*	1395	*
		mean	1058	121.1				
933	15.6	1	6435	465.1	135	202.5	6300	262.6
		2	46755	2802.2	585	877.5	46170	1924.7
		mean	26595	1633.6				
934	28.0	1	2115	230.0	1980	179.6	135	50.4
		2	2205	199.8	2205	199.8	0	0
		mean	2160	214.9				
935	34.3	1	225	11.2	225	11.2	0	0
		2	225	8.2	225	8.2	0	0
		mean	225	9.7				
936	6.4	1	7695	628.4	90	24.9	7605	603.5
		2	18675	1525.1	9180	909.0	9495	616.1
		mean	13185	1076.8				
937	8.8	1	2295	202.5	945	*	1350	*
		2	1755	214.0	495	*	1260	*
		mean	2025	208.3				
938	37.2	1	1125	61.3	1125	61.3	0	0
		2	270	16.3	270	16.3	0	0
		mean	698	38.8				
939	57.0	1	3195	141.4	3195	141.4	0	0
		2	3420	148.4	3420	148.4	0	0
		mean	3308	144.9				

Appendix 1. Continued. Lake Erie 1992.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
940	48.8	1	7380	370.4	7380	370.4	0	0
		2	5085	276.8	5085	276.8	0	0
		mean	6232	323.6				
941	37.0	1	225	8.1	180	*	45	*
		2	315	26.3	90	*	225	*
		mean	270	17.2				
942	15.9	1	18720	2490.7	720	121.0	18000	2369.7
943	12.6	1	135	4.1	135	4.1	0	0
		2	90	6.0	90	6.0	0	0
		mean	112	5.1				
944	16.8	1	14805	2549.4	1755	771.5	13050	1777.9
945	21.6	1	315	47.8	180	*	135	*
		2	315	59.0	135	*	180	*
		mean	315	53.4				
946	23.5	1	630	23.2	180	*	450	*
		2	2115	62.4	1125	7.0	990	55.4
		mean	1372	42.8				
947	15.7	1	45	9.0	0	0	45	9.0
		2	45	17.1	0	0	45	17.1
		mean	45	13.0				
948	12.8	1	1125	147.0	0	0	1125	147.0
		2	45	0.2	0	0	45	0.2
		mean	585	73.6				
949	22.1	1	810	60.8	45	*	765	*
		2	405	28.4	0	0	405	28.4
		mean	608	44.6				
950	8.5	1	45	0.6	0	0	45	0.6
		2	0	0	0	0	0	0
		mean	22	0.3				
951	20.4	1	585	21.3	0	0	585	21.3
952	22.7	1	45	4.9	0	0	45	4.9
		2	90	9.1	0	0	90	9.1
		mean	68	11.8				

Appendix 1. Continued. Lake Erie 1992.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
953	23.9	1	270	0.6	270	0.6	0	0
		2	0	0	0	0	0	0
		mean	135	0.3				
954	24.2	1	45	5.9	0	0	45	5.9
		2	0	0	0	0	0	0
		mean	22	3.0				
955	20.3	1	90	0.3	90	0.3	0	0
		2	135	12.8	45	*	90	*
		mean	112	6.5				
956	10.0	1	3442	854.9	45	32.2	3397	822.7
957	21.2	1	0	0	0	0	0	0
958	11.4	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
959	11.2	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	1890	552.2	0	0	1890	552.2
		4	4815	648.7	0	0	4815	648.7
		5	6570	1915.6	45	75.2	6525	1840.4
		mean	2655	623.3				
960	21.3	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
961	21.3	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
962	19.5	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
963	15.6	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
964	9.8	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				

Appendix 1. Continued. Lake Erie 1992.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
965	14.0	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
966	10.5	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
967	11.6	1	90	4.0	0	0	90	4.0
		2	45	3.3	0	0	45	3.3
		mean	68	3.7				
968	10.6	1	2655	271.9	45	8.9	2610	263.0
		2	1620	91.9	0	0	1620	91.9
		mean	2138	181.9				
969	7.9	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
970	10.7	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
971	9.3	1	90	9.9	0	0	90	9.9
		2	0	0	0	0	0	0
		mean	45	5.0				
972	8.6	1	270	5.9	0	0	270	5.9
		2	11925	333.7	0	0	11925	333.7
		mean	6098	169.8				
973	6.2	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		mean	0	0				
974	8.2	1	90	4.2	0	0	90	4.2
		2	45	0.2	0	0	45	0.2
		mean	68	2.2				

Appendix 2. Lake Erie 1993. *Dreissena* density (no./m²) and biomass (wet weight with the shell g/m²) measurements for 1mm mesh portion. All data from the 1993 survey is included in this appendix while only sites matching 1992 and 1998 were used in the statistical analysis.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
932	21.0	1	495	35.7	225	16.0	270	19.7
		2	2475	271.8	1710	201.7	765	70.1
		3	360	28.5	270	21.2	90	7.2
		4	2205	198.7	1350	98.3	855	100.4
		mean	1384	133.7				
933	13.5	1	765	0.7	225	0.2	540	0.6
		2	720	4.9	540	1.4	180	3.5
		3	2835	69.3	855	9.1	1980	60.2
		4	10800	557.5	4680	184.1	6120	373.4
		mean	3780	158.1				
935	34.0	1	5125	547.6	5125	547.6	0	0
		2	500	24.6	375	24.1	125	0.5
		3	5500	264.5	5500	264.5	0	0
		mean	3708	278.9				
936	13.0	1	17750	3027.8	12750	2182.9	5000	844.9
		2	875	60.0	875	60.0	0	0
		3	750	55.8	750	55.8	0	0
		mean	6458	1047.8				
937	8.3	1	585	35.9	585	35.9	0	0
		2	15120	1099.9	10260	499.8	4860	600.1
		3	7740	2035.1	6390	1887.3	1350	147.8
		4	765	68.8	450	26.1	315	42.7
		5	90	10.0	90	10.0	0	0
		6	10170	1090.1	6705	487.5	3465	536.7
		7	10350	1066.9	6840	527.5	3510	539.3
		8	4005	333.3	3240	270.2	765	63.0
		9	765	112.5	720	105.5	45	7.1
		10	180	16.6	180	16.6	0	0
		11	3060	326.6	2250	211.1	810	115.5
		12	27225	3457.1	19125	2128.0	8100	1329.1
		13	16155	1762.5	12330	958.7	3825	803.7
		14	585	61.0	450	51.6	135	9.4
		15	4950	653.9	3825	476.1	1125	177.8
		16	1710	221.5	1530	189.9	180	31.7
		17	18900	2148.4	14085	1312.9	4815	835.5
		18	2745	272.0	2745	272.0	0	0
		19	1890	198.0	1665	170.1	225	27.8
		20	7290	766.4	6660	655.5	630	110.9
		21	765	62.5	765	62.5	0	0
		22	4050	284.4	3465	225.5	540	58.9
		23	4455	447.9	3780	358.4	675	89.4
		24	1260	131.7	1125	106.6	135	25.1

Appendix 2. Continued. Lake Erie 1993.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
937 cont.		25	1170	154.1	945	126.4	225	27.7
		26	7245	901.5	6525	863.8	720	37.6
		27	1665	191.9	1665	191.9	0	0
		28	5490	605.9	5490	605.9	0	0
		29	1800	249.3	1800	249.3	0	0
		mean	5592	620.7				
938	36.0	1	6125	412.4	6125	412.4	0	0
		2	14250	931.0	14250	931.0	0	0
		3	9250	564.0	9250	564.0	0	0
		4	3915	612.5	3915	612.5	0	0
		5	5805	1024.6	5760	1023.4	45	1.2
		6	3600	533.6	3600	533.6	0	0
		7	990	86.8	990	86.8	0	0
		8	2925	346.5	2925	346.5	0	0
		9	720	83.4	720	83.4	0	0
		10	8640	1561.6	8595	1560.1	45	1.5
		11	7650	1542.7	7650	1542.7	0	0
		12	405	29.8	405	29.8	0	0
		13	1755	136.4	1755	136.4	0	0
		14	4230	357.9	4230	357.9	0	0
		15	3060	277.5	3015	273.7	45	3.7
		16	19260	1529.0	19170	1511.8	90	17.2
		17	2385	156.0	2385	156.0	0	0
		18	2880	262.4	2880	262.4	0	0
		19	720	139.2	720	139.2	0	0
		20	1440	273.6	1440	273.6	0	0
		21	315	39.7	315	39.7	0	0
		22	720	122.2	720	122.2	0	0
		mean	4593	501.0				
939	56.0	1	3250	259.0	3250	259.0	0	0
		2	750	28.3	750	28.3	0	0
		3	14500	743.8	14500	743.8	0	0
		mean	6167	343.7				
940	47.5	1	4875	378.8	4875	378.8	0	0
		2	13000	604.2	13000	604.2	0	0
		3	750	18.0	750	18.0	0	0
		mean	6208	333.7				

Appendix 2. Continued. Lake Erie 1993.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
941	36.0	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	375	0.4	375	0.4	0	0
		mean	125	0.1				
942	16.0	1	25560	3226.1	10080	1602.9	15480	1623.2
		2	11655	2066.1	4050	856.3	7605	1209.9
		3	2160	455.9	675	133.7	1485	322.2
		4	1305	257.6	450	124.7	855	132.9
		mean	10170	1501.4				
943	9.8	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		4	0	0	0	0	0	0
		mean	0	0				
944	17.2	1	0	0	0	0	0	0
		2	315	6.3	0	0	315	6.3
		3	7920	616.1	3105	362.6	4815	253.6
		4	12195	1574.3	4410	1180.0	7785	394.3
		mean	5108	549.2				
945	21.3	1	135	49.3	45	49.1	90	0.2
		2	8865	2129.2	4590	913.5	4275	1215.6
		3	45	0.2	45	0.2	0	0
		4	450	118.3	315	113.4	135	4.8
		mean	2374	574.2				
946	23.0	1	12555	1372.1	9855	1078.8	2700	293.3
		2	1125	107.7	1035	96.1	90	11.7
		3	11250	1289.5	9945	1128.6	1305	160.9
		4	7830	764.4	5535	207.5	2295	556.9
		mean	8190	883.4				
948	12.8	1	1125	203.6	720	47.1	405	156.5
		2	0	0	0	0	0	0
		3	17640	7580.9	13815	5564.5	3825	2016.4
		4	0	0	0	0	0	0
		mean	4691	1946.1				
950	8.3	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		4	0	0	0	0	0	0
		mean	0	0				

Appendix 2. Continued. Lake Erie 1993.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
951	20.2	1	3465	20.2	3420	19.5	45	0.7
		2	1890	27.4	1890	27.4	0	0
		3	6480	192.1	6435	192.1	45	0
		4	1170	17.7	1125	16.3	45	1.4
		mean	3251	64.3				
952	22.0	1	0	0	0	0	0	0
		2	125	0.6	125	0.6	0	0
		3	250	3.1	250	3.1	0	0
		mean	125	1.2				
954	24.2	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	125	0.02	125	0.02	0	0
		mean	42	0.008				
955	20.8	1	125	0.6	0	0	125	0.6
		2	125	0.03	125	0.03	0	0
		3	0	0	0	0	0	0
		mean	83	0.2				
956	11.0	1	315	134.3	45	14.2	270	120.1
		2	45	42.7	0	0	45	42.7
		3	675	437.7	90	27.9	585	409.9
		4	90	24.4	45	0.003	45	24.4
		mean	281	159.8				
957	21.0	1	125	0.08	125	0.08	0	0
		2	125	0.6	125	0.6	0	0
		3	125	0.02	125	0.02	0	0
		mean	125	0.2				
958	11.3	1	0	0	0	0	0	0
		2	315	321.9	0	0	315	321.9
		3	0	0	0	0	0	0
		4	0	0	0	0	0	0
		mean	79	80.5				
959	13.4	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		4	90	0.6	90	0.6	0	0
		mean	22	0.1				
960	21.3	1	125	0.5	0	0	125	0.5
		2	250	2.1	0	0	250	2.1
		3	0	0	0	0	0	0
		mean	125	0.9				

Appendix 2. Continued. Lake Erie 1993.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
961	20.7	1	125	0.4	0	0	125	0.4
		2	500	8.7	250	5.8	250	2.9
		3	250	5.3	250	5.3	0	0
		mean	292	4.8				
962	19.1	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	125	0.7	125	0.7	0	0
		mean	42	0.2				
963	15.0	1	135	31.9	0	0	135	31.9
		2	675	7.7	630	7.6	45	0.05
		3	30780	2864.7	26505	410.2	4275	2454.5
		mean	10530	968.1				
964	9.8	1	540	147.3	0	0	540	147.3
		2	5760	1880.5	90	107.7	5670	1772.8
		3	4185	2061.6	45	34.5	4140	2027.2
		mean	3495	1363.2				
965	13.5	1	250	6.1	250	6.1	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		mean	83	2.0				
966	10.5	1	125	0.9	0	0	125	0.9
		2	1125	13.1	0	0	1125	13.1
		3	250	2.0	0	0	250	2.0
		mean	500	5.3				
967	11.5	1	0	0	0	0	0	0
		2	500	3.5	0	0	500	3.5
		3	375	2.0	0	0	375	2.0
		mean	292	1.8				
968	10.5	1	2970	352.8	0	0	2970	352.8
		2	4860	455.4	0	0	4860	455.4
		3	2655	215.6	0	0	2655	215.6
		mean	2621	256.0				
969	7.8	1	0	0	0	0	0	0
		2	125	0.8	0	0	125	0.8
		3	0	0	0	0	0	0
		mean	42	0.3				

Appendix 2. Continued. Lake Erie 1993.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
970	10.5	1	250	13.0	0	0	250	13.0
		2	5750	143.3	0	0	5750	143.3
		3	19935	5617.3	0	0	19935	5617.3
		4	270	25.4	0	0	270	25.4
		5	90	3.8	0	0	90	3.8
		6	28530	3844.4	0	0	28530	3844.4
		7	315	13.5	0	0	315	13.5
		8	0	0	0	0	0	0
		9	135	6.3	0	0	135	6.3
		10	45	1.9	0	0	45	1.9
		11	405	8.1	0	0	405	8.1
		12	6975	673.8	0	0	6975	673.8
		13	0	0	0	0	0	0
		14	45	0.9	0	0	45	0.9
		15	47385	7240.4	0	0	47385	7240.4
		16	305	16.0	0	0	305	16.0
		17	45	0.5	0	0	45	0.5
		mean	6499	1035.8				
971	8.9	1	250	1.9	0	0	250	1.9
		2	4000	812.5	0	0	4000	812.5
		3	250	1.0	0	0	250	1.0
		mean	1500	271.8				
972	8.5	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	125	6.1	0	0	125	6.1
		mean	42	2.0				
973	6.2	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		mean	0	0				
974	8.2	1	375	1.6	0	0	375	1.6
		2	125	1.0	0	0	125	1.0
		3	125	1.0	0	0	125	1.0
		mean	208	1.2				
WC1	16.3	1	585	591.7	540	587.0	45	4.7
		2	225	263.3	180	146.2	45	117.1
		3	3735	4622.4	990	329.4	2745	4293.0
		4	1980	925.2	0	0	1980	925.2
		5	450	212.7	0	0	450	212.7
		6	14715	2865.9	45	21.2	14670	2844.8
		7	1710	1997.5	1080	878.1	630	1119.3
		8	1080	975.4	945	616.2	135	359.2
		9	5985	6143.8	4050	2628.8	1935	3515.1

Appendix 2. Continued. Lake Erie 1993.

Site #	Depth (m)	Rep #	Combined <i>Dreissena</i>		<i>D. bugensis</i>		<i>D. polymorpha</i>	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
WC1 cont.		10	45	10.8	45	10.8	0	0
		11	6480	4116.3	6075	3453.5	405	663.0
		12	0	0	0	0	0	0
		13	3780	3937.7	3150	2684.5	630	1253.2
		14	4275	4356.1	3510	2575.2	765	1780.8
		15	45	36.7	0	0	45	36.7
		16	270	173.7	225	83.3	45	90.3
		17	1350	728.7	1215	552.7	135	176.1
		18	315	57.3	315	57.3	0	0
		19	0	0	0	0	0	0
		20	90	51.2	90	51.2	0	0
		21	0	0	0	0	0	0
		22	4410	3272.2	4230	2849.5	180	422.7
		23	4455	1452.2	4365	1360.1	90	92.2
		24	2700	973.7	2700	973.7	0	0
		25	1170	356.7	1125	238.1	45	118.7
		mean	2390	1488.7				
WC3	21.6	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		4	0	0	0	0	0	0
		5	0	0	0	0	0	0
		6	0	0	0	0	0	0
		7	90	2.0	90	2.0	0	0
		8	0	0	0	0	0	0
		9	135	2.4	135	2.4	0	0
		10	90	4.0	90	4.0	0	0
		11	0	0	0	0	0	0
		12	0	0	0	0	0	0
		13	90	4.4	90	4.4	0	0
		14	90	1.9	90	1.9	0	0
		15	45	2.0	45	2.0	0	0
		16	0	0	0	0	0	0
		17	225	10.8	225	10.8	0	0
		18	180	7.6	180	7.6	0	0
		19	540	94.8	225	88.3	315	6.5
		20	270	75.0	180	71.7	90	3.3
		21	180	32.2	135	30.4	45	1.8
		22	45	10.7	45	10.7	0	0
		mean	90	11.3				

Appendix 2. Continued. Lake Erie 1993.

Site #	Depth (m)	Rep #	Combined Dreissena		D. bugensis		D. polymorpha	
			Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)	Density (no./m ²)	Biomass (g/m ²)
W1	9.6	1	0	0	0	0	0	0
		2	0	0	0	0	0	0
		3	0	0	0	0	0	0
		4	45	1.9	0	0	45	1.9
		5	0	0	0	0	0	0
		6	315	9.8	0	0	315	9.8
		7	0	0	0	0	0	0
		8	0	0	0	0	0	0
		9	0	0	0	0	0	0
		10	135	9.2	0	0	135	9.2
		11	13455	2514.7	0	0	13455	2514.7
		12	0	0	0	0	0	0
		13	0	0	0	0	0	0
		14	0	0	0	0	0	0
		15	0	0	0	0	0	0
		16	0	0	0	0	0	0
		17	0	0	0	0	0	0
		18	45	0.4	0	0	45	0.4
		19	0	0	0	0	0	0
		20	0	0	0	0	0	0
		21	0	0	0	0	0	0
		22	0	0	0	0	0	0
		mean	636	115.3				

Appendix 3. Lake Erie site identification and locations for 1992.

Site Number	Depth (m)	Latitude	Longitude
928	55.6	42° 34.22'	79° 36.85'
929	60.5	42° 32.08	79° 50.32
930	58.5	42° 28.95	80° 02.80
931	8.5	42° 50.98	78° 56.53
932	21.3	42° 47.50	79° 12.55
933	15.6	42° 49.00	79° 34.08
934	28.0	42° 42.52	79° 30.47
935	34.3	42° 35.55	79° 27.97
936	6.4	42° 28.45	79° 24.45
937	8.8	42° 42.90	80° 14.72
938	37.2	42° 37.98	80° 03.43
939	57.0	42° 33.98	79° 54.85
940	48.8	42° 26.48	79° 50.08
941	37.0	42° 19.58	79° 50.03
942	15.9	42° 15.43	79° 49.97
943	12.6	42° 34.43	80° 38.05
944	16.8	42° 31.90	80° 38.42
945	21.6	42° 22.02	80° 38.27
946	23.5	42° 09.92	80° 38.50
947	15.7	41° 59.42	80° 38.47
948	12.8	41° 57.53	80° 38.92
949	22.1	42° 15.00	81° 06.50
950	8.5	42° 35.22	81° 26.55
951	20.4	42° 28.55	81° 26.50
952	22.7	42° 21.53	81° 26.45
953	23.9	42° 11.02	81° 26.43
954	24.2	42° 01.53	81° 26.62
955	20.3	41° 48.00	81° 26.50
956	10.0	41° 41.32	81° 26.95
957	21.2	41° 41.00	81° 44.45
958	11.4	41° 31.50	81° 42.47
959	11.2	42° 11.42	82° 11.20
960	21.3	42° 05.00	82° 10.98
961	21.3	42° 54.47	82° 10.92
962	19.5	41° 43.00	82° 11.07
963	15.6	41° 34.47	82° 11.03
964	9.8	41° 29.03	82° 10.92
965	14.0	41° 30.00	82° 30.02
966	10.5	41° 59.00	82° 37.50
967	11.6	41° 53.50	82° 39.98
968	10.6	41° 44.48	82° 44.00
969	7.9	41° 36.50	82° 55.53
970	10.7	41° 49.57	82° 58.55
971	9.3	41° 56.87	83° 03.02
972	8.6	41° 52.17	83° 11.90
973	6.2	41° 47.43	83° 20.00
974	8.2	41° 43.40'	83° 09.30'